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Raymond et al.

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(54) **SLANT LENS INTERLACING WITH LINEARLY ARRANGED SETS OF LENSES**

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Related U.S. Application Data

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(60) Provisional application No. 61/797,145, filed on Nov. 30, 2012.

(51) **Int. Cl.**

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G02B 3/00	(2006.01)
G02B 27/22	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 3/0037*** (2013.01); ***G02B 3/005*** (2013.01); ***G02B 27/2214*** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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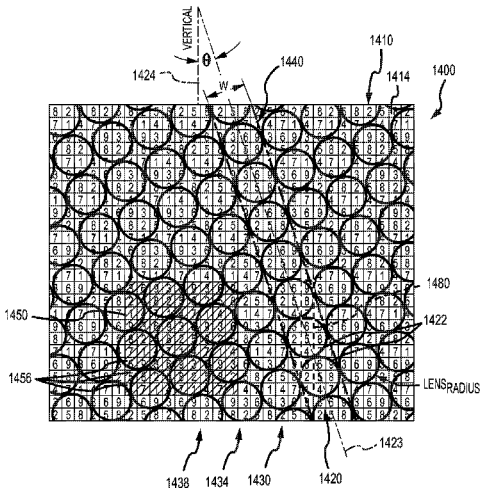
(57) **ABSTRACT**

An optical product that includes a transparent lens sheet, which has a first side with a plurality of side-by-side sets of linearly arranged lenses. Each of the sets of lenses is at a slant angle in the range of 10 to 46 degrees from a vertical or a horizontal axis of the lens sheet. The product includes an image layer that includes pixels from a number of digital images. The pixels are arranged in a pattern of pixel locations providing non-orthogonal interlacing of the digital images relative to each of the sets of the linearly arranged lenses. The pattern of pixel locations aligns a number of the pixels from each of the digital images to be parallel to a line extending through a center of the linearly arranged lenses in each set. Each of the linearly arranged lenses may have a round base, a hexagonal base, or a square base.

24 Claims, 17 Drawing Sheets



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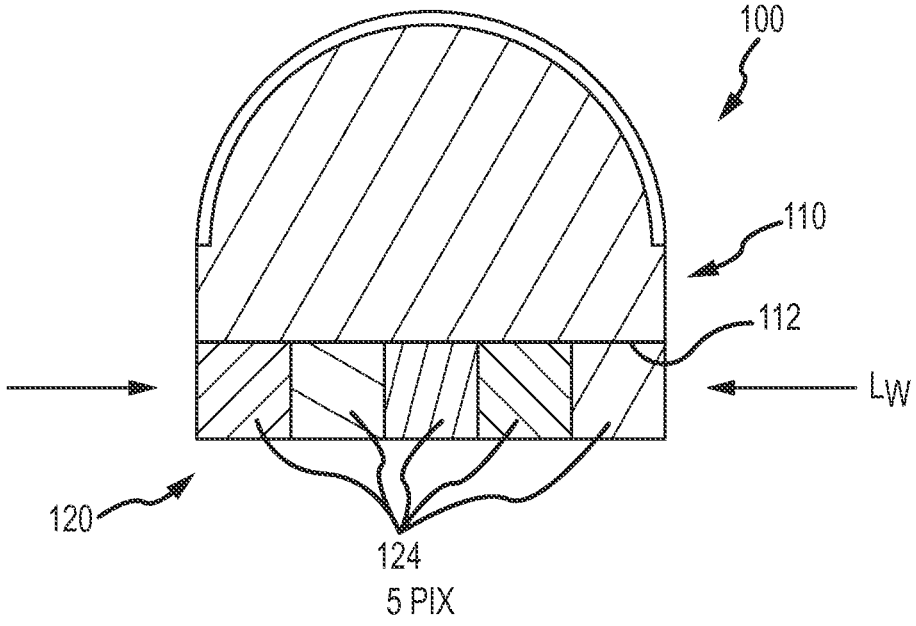

FIG.1
PRIOR ART

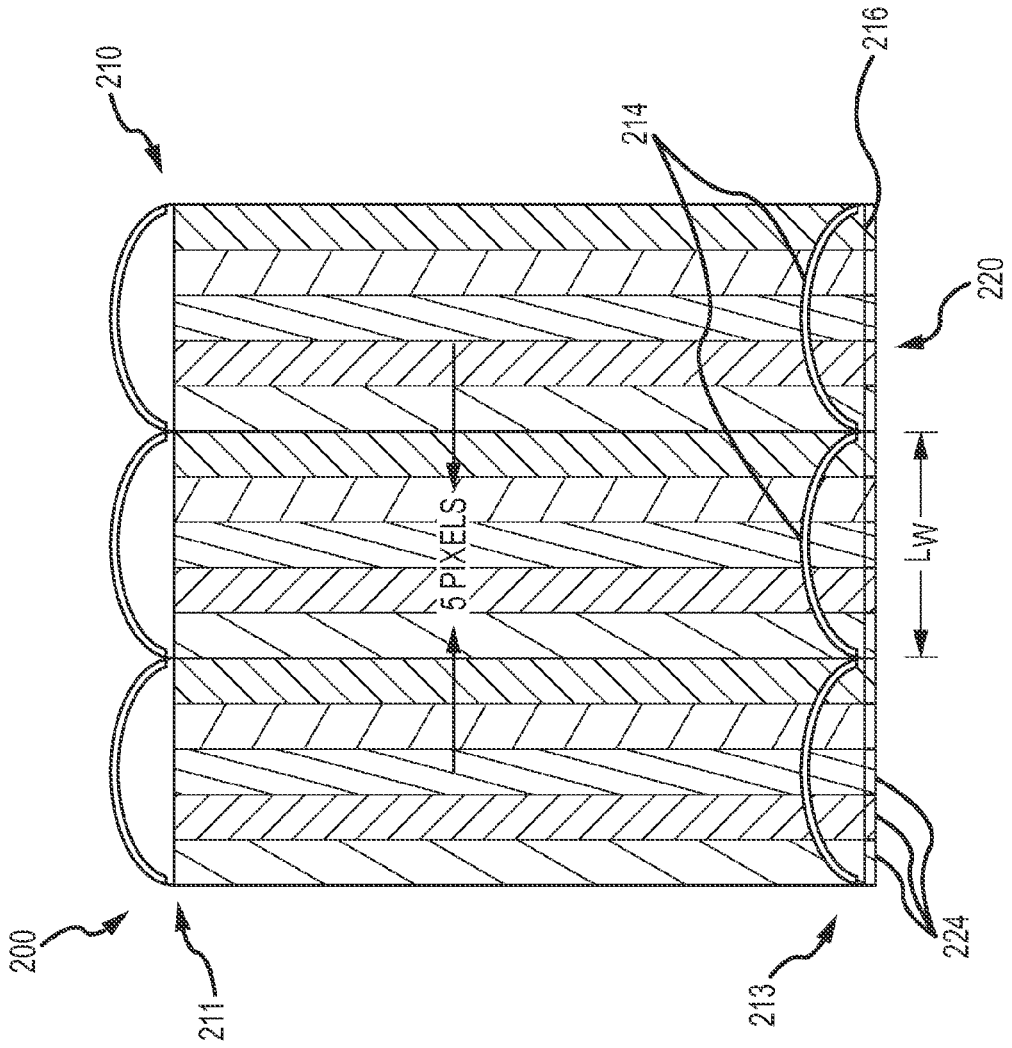

FIG.2
PRIOR ART

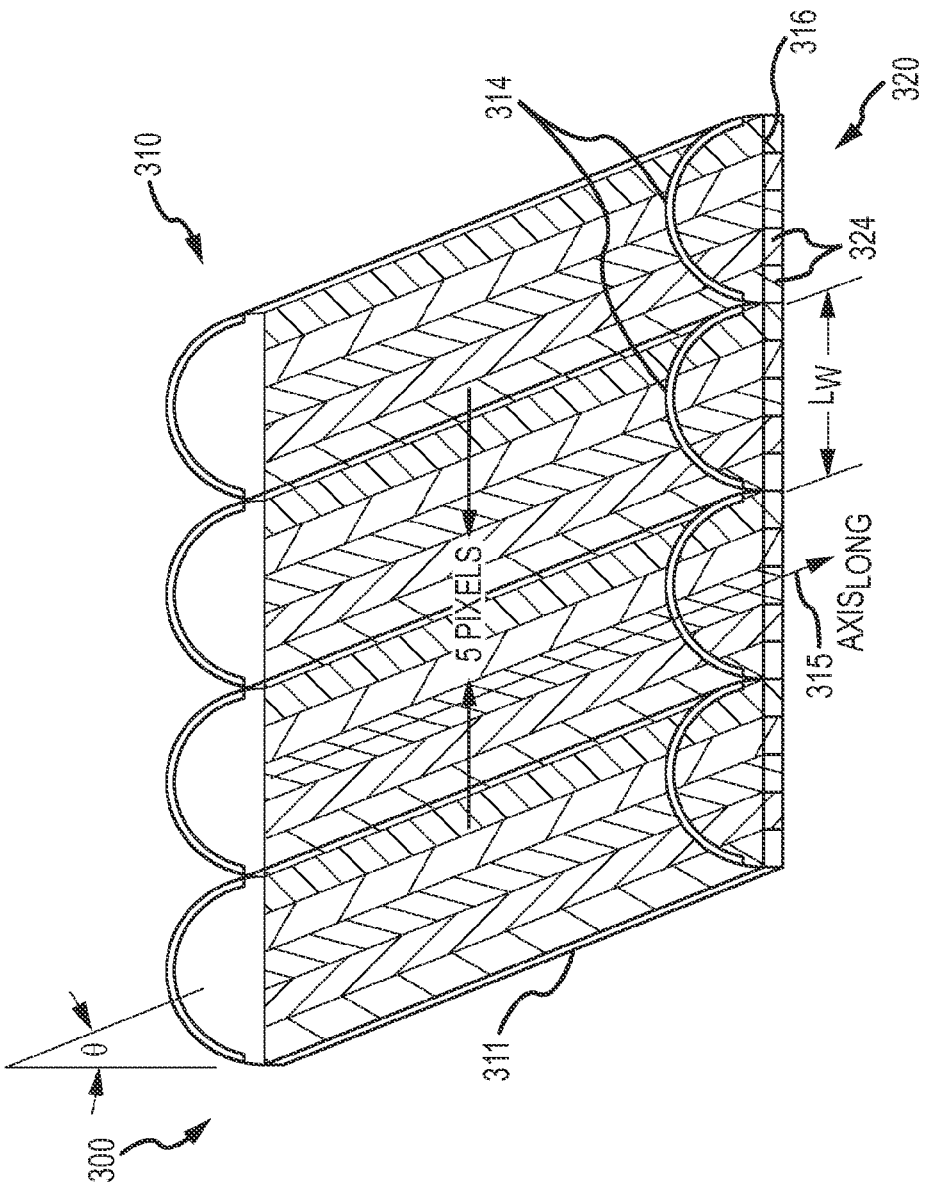

FIG.3
PRIOR ART

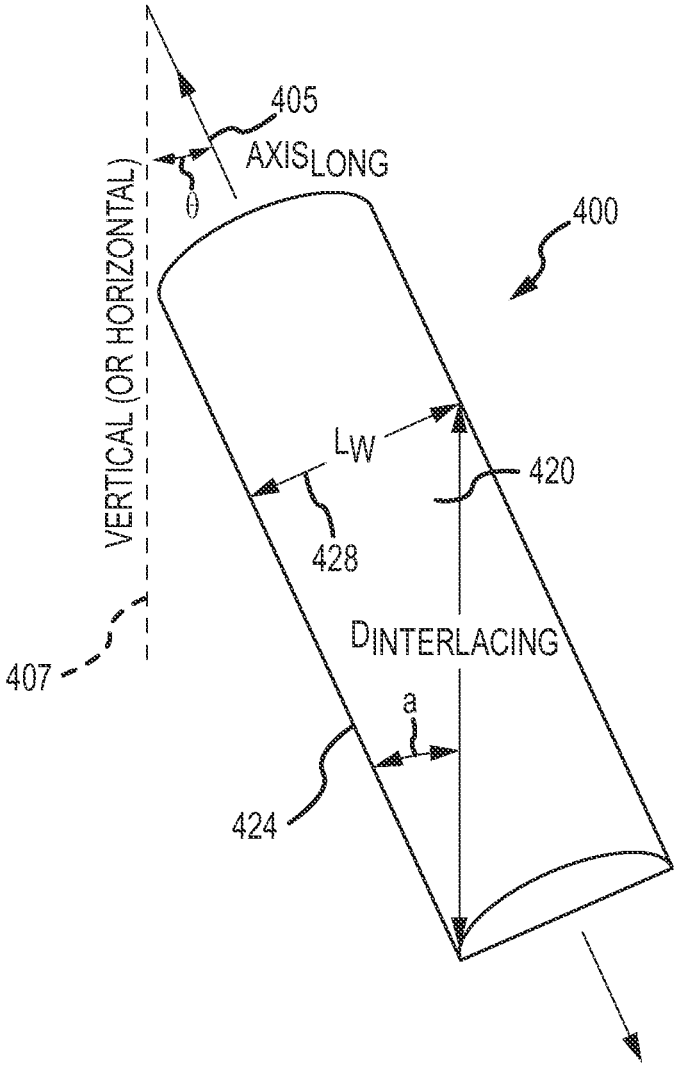
405
AXIS LONG
θ
400
VERTICAL (OR HORIZONTAL)
LW
420
428
DINTERLACING
407
a
424

FIG.4

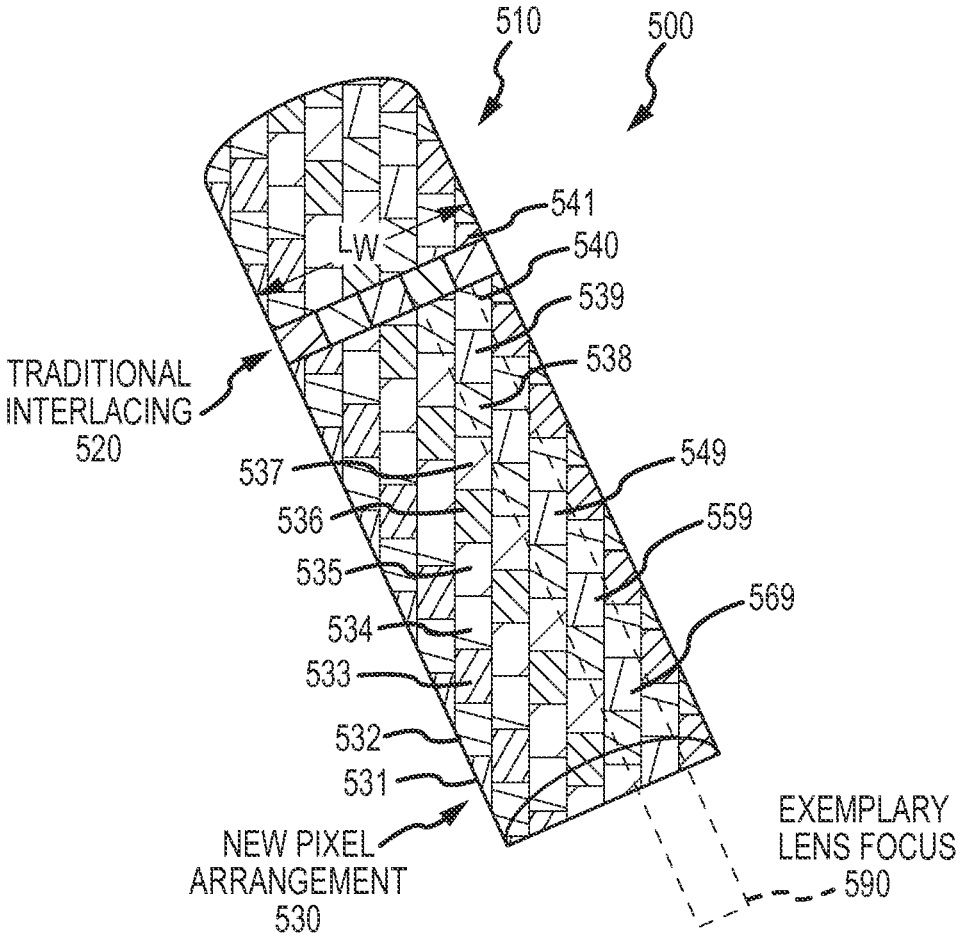
510
500
541
LW
540
539
538
TRADITIONAL
INTERLACING
520
549
537
559
536
535
569
534
533
532
531
EXEMPLARY
LENS FOCUS
590
NEW PIXEL
ARRANGEMENT
530

FIG.5

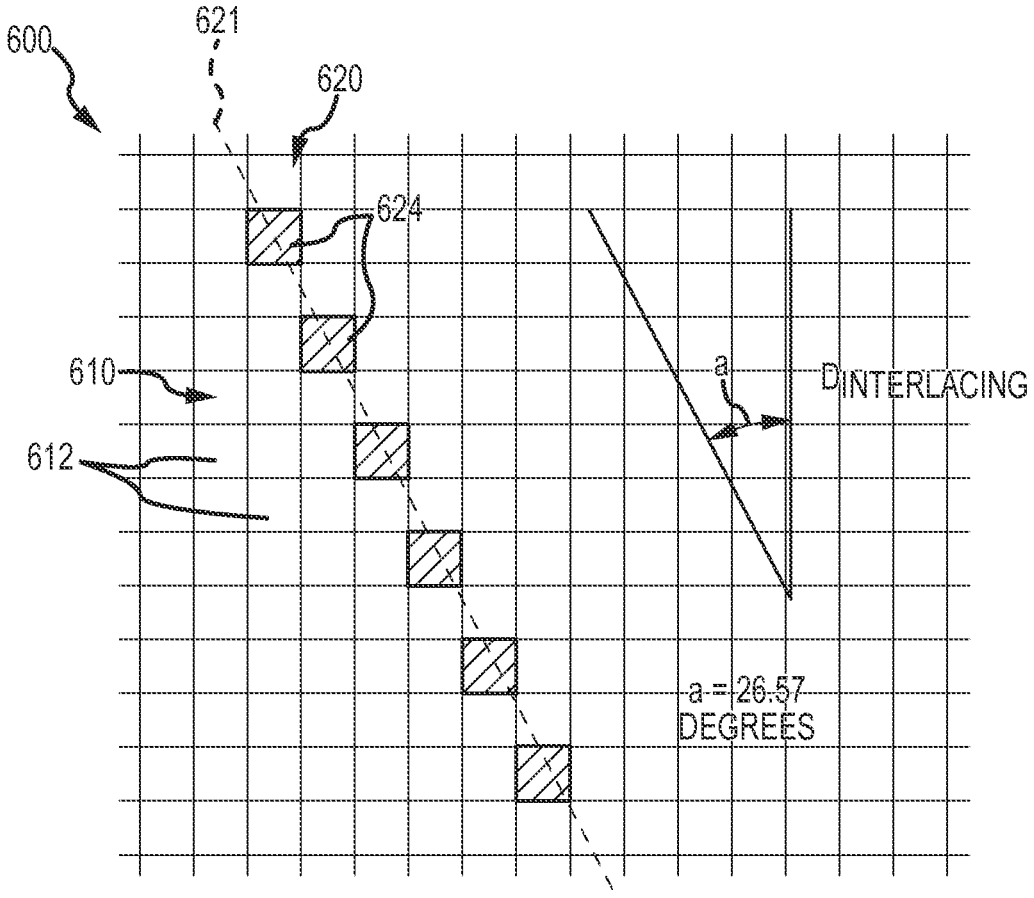

FIG.6

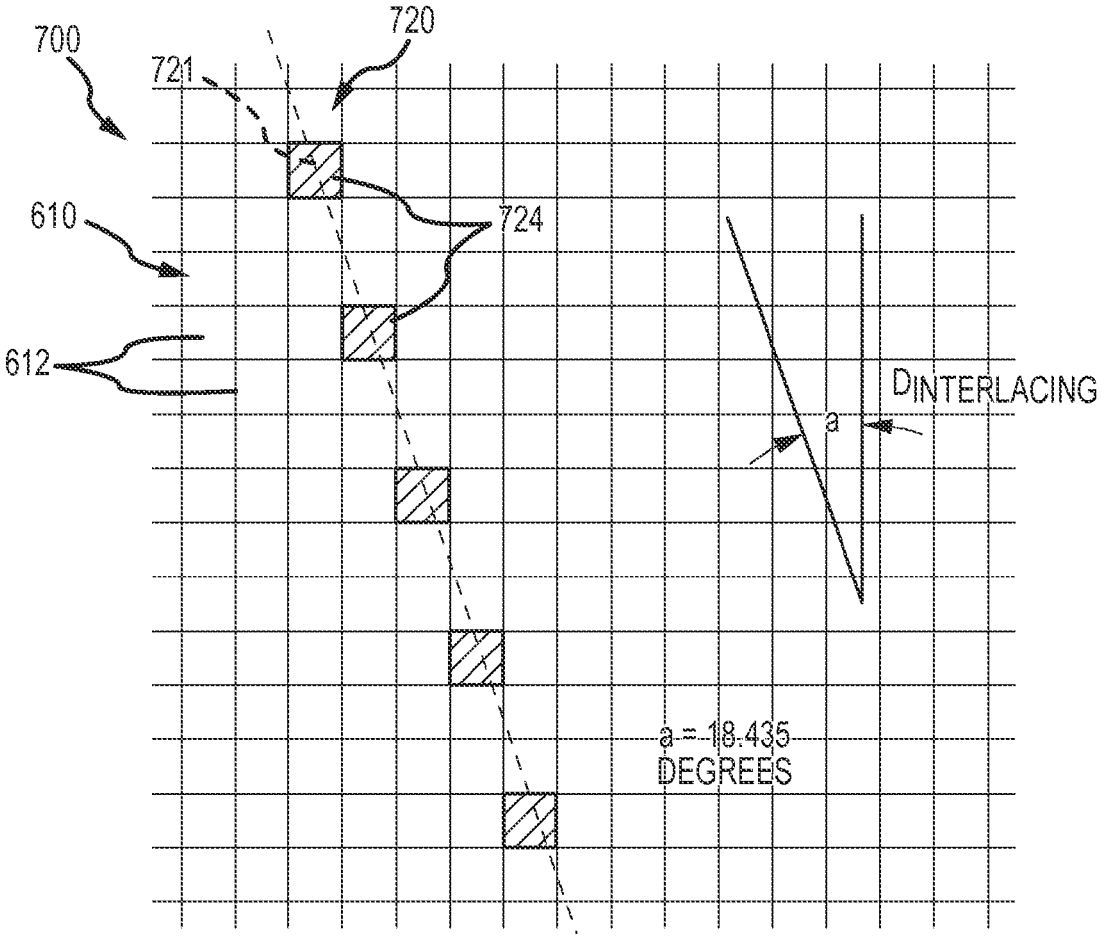

FIG.7

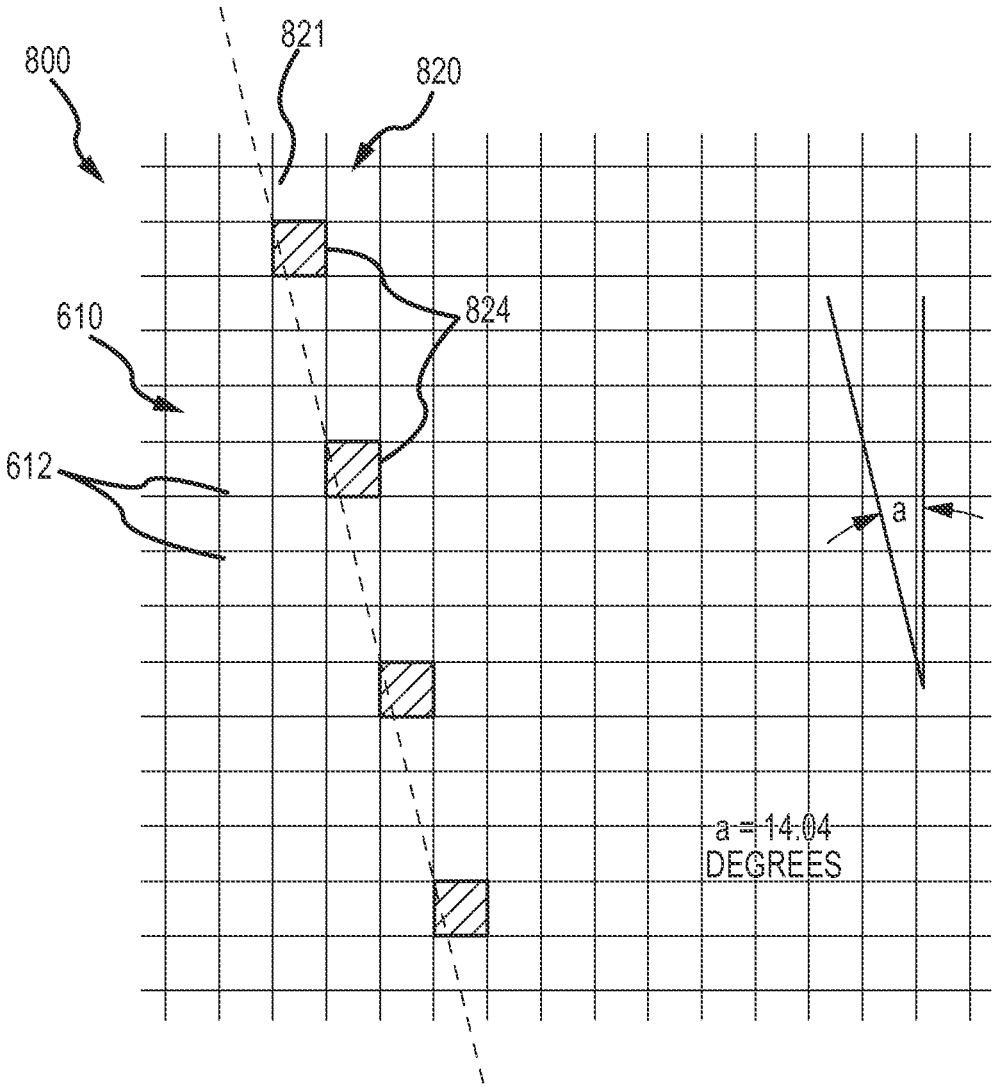

FIG.8

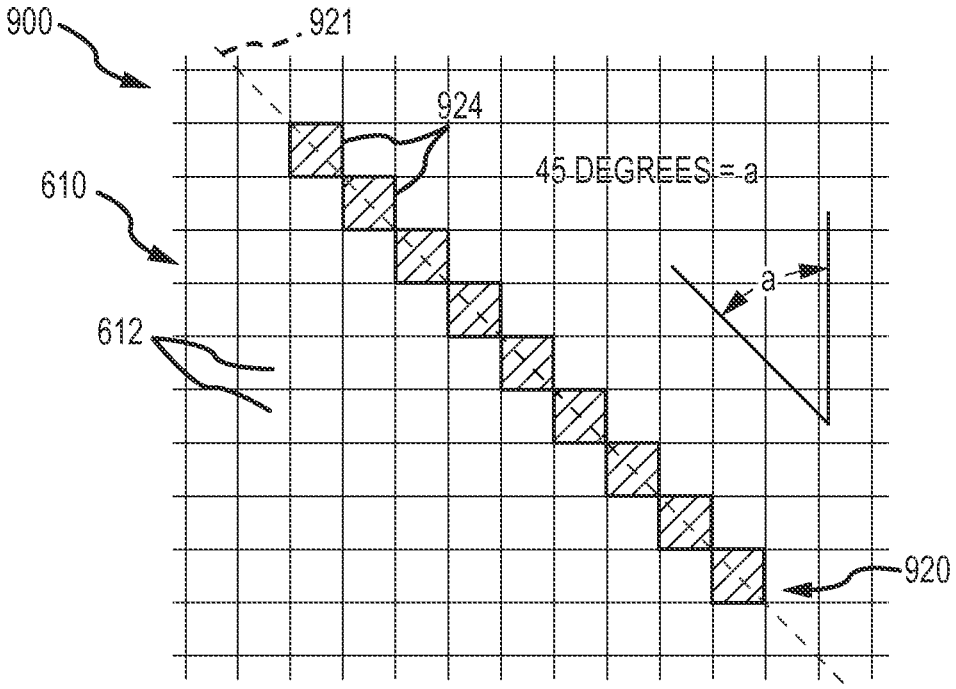

FIG.9

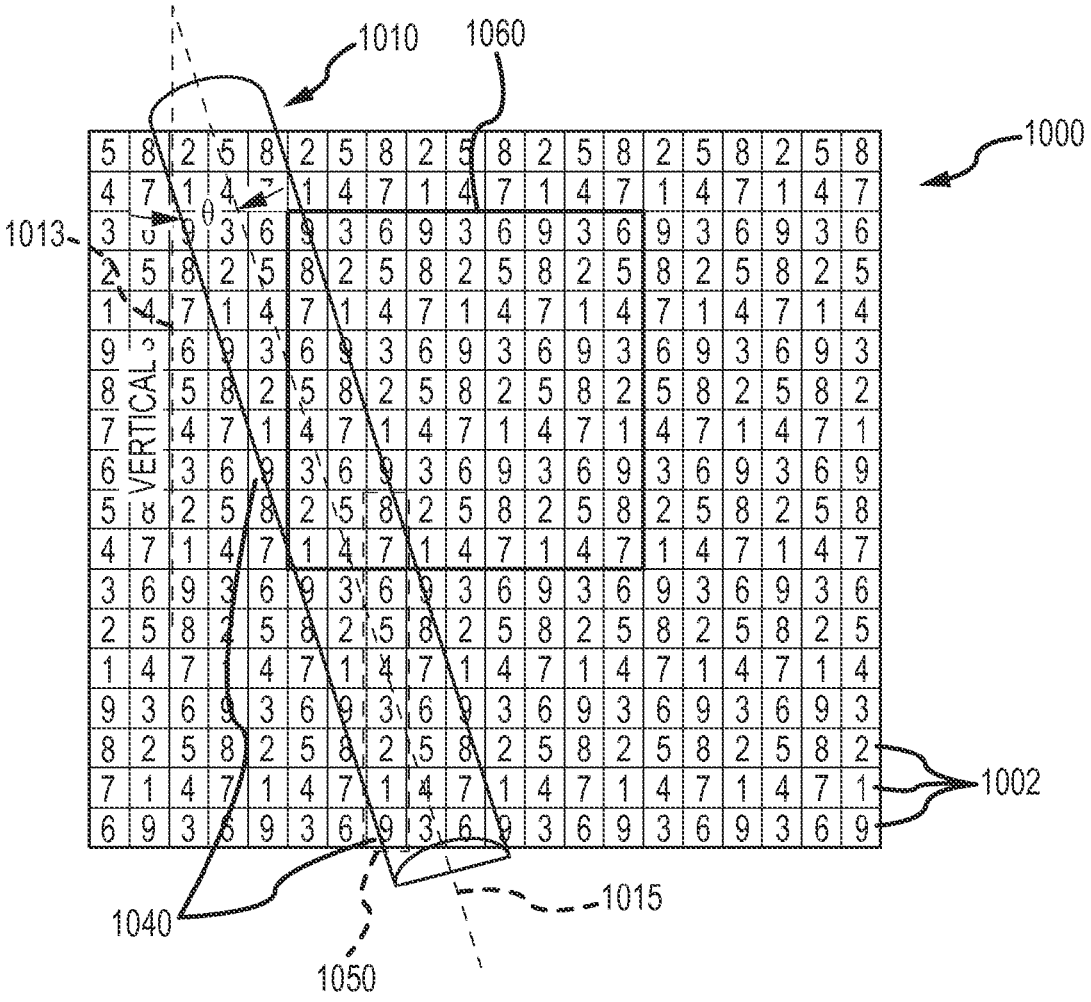

FIG.10

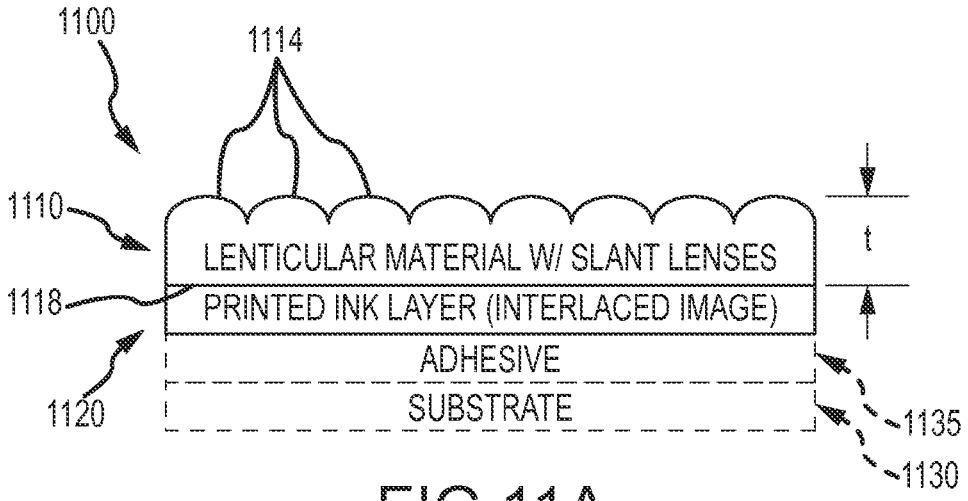

FIG.11A

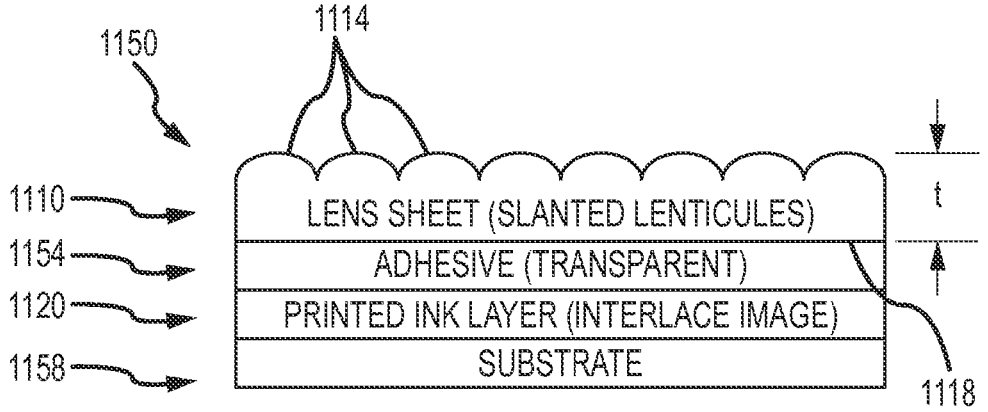

FIG.11B

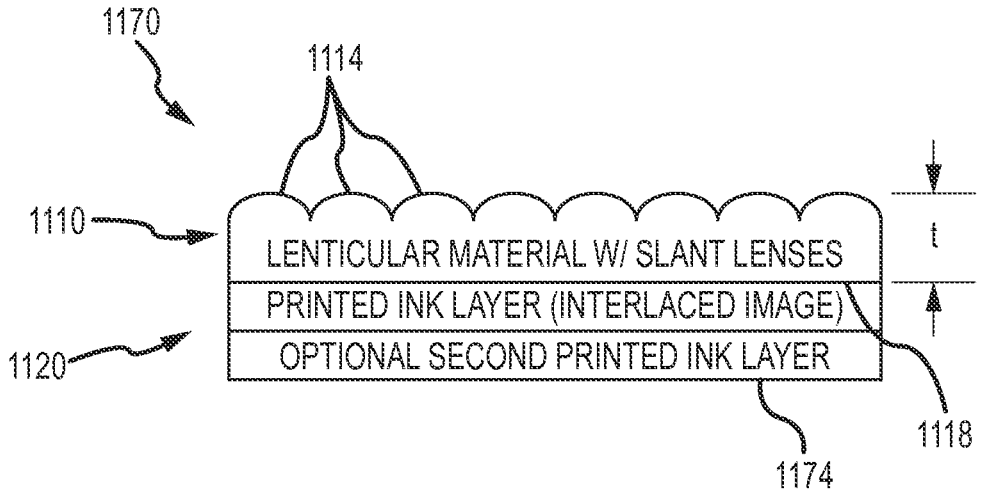
1170
1114
1110
LENTICULAR MATERIAL W/ SLANT LENSES
PRINTED INK LAYER (INTERLACED IMAGE)
OPTIONAL SECOND PRINTED INK LAYER
t
1120
1118
1174

FIG.11C

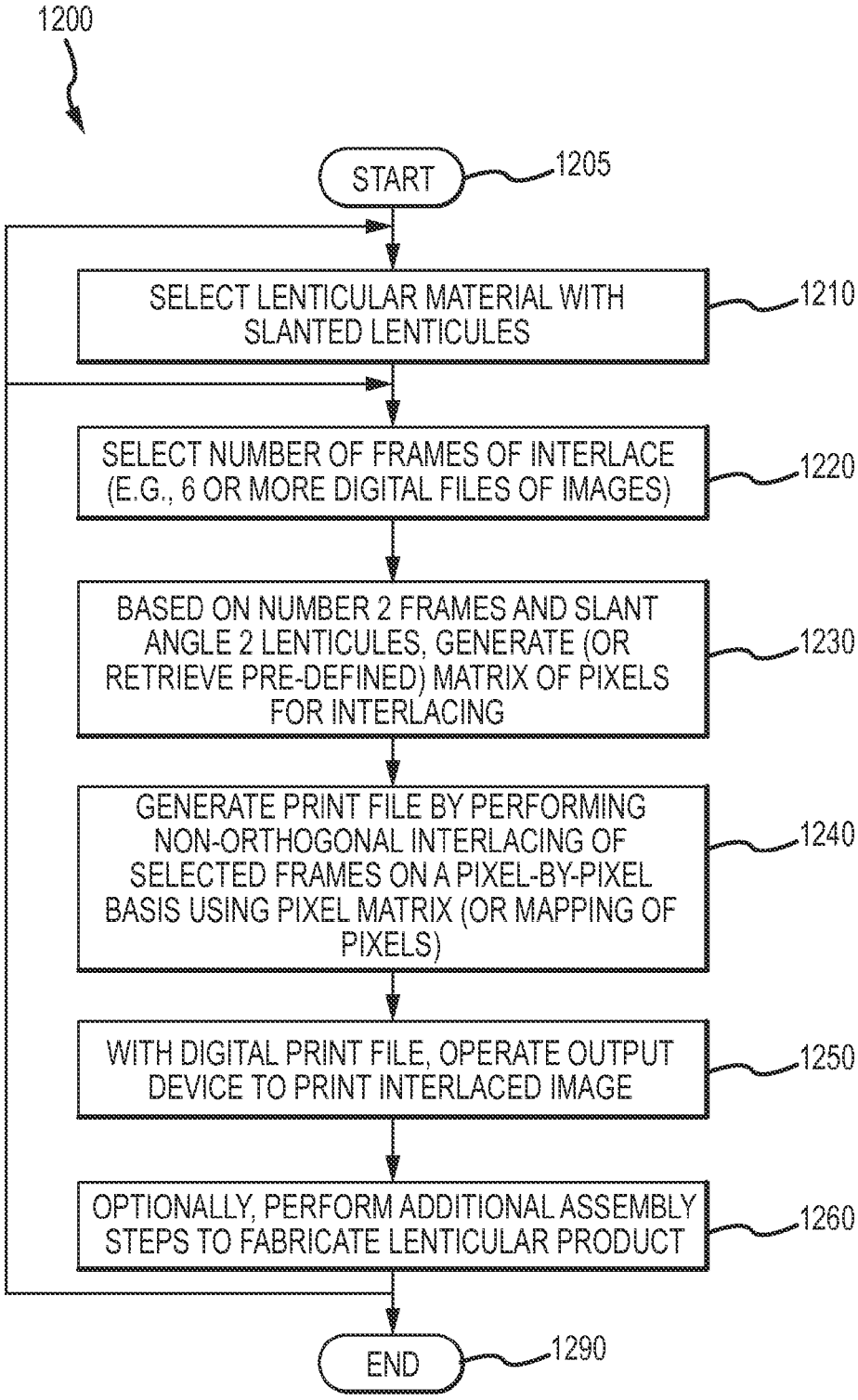
1200
START
1205
SELECT LENTICULAR MATERIAL WITH SLANTED LENTICULES
1210
SELECT NUMBER OF FRAMES OF INTERLACE (E.G., 6 OR MORE DIGITAL FILES OF IMAGES)
1220
BASED ON NUMBER 2 FRAMES AND SLANT ANGLE 2 LENTICULES, GENERATE (OR RETRIEVE PRE-DEFINED) MATRIX OF PIXELS FOR INTERLACING
1230
GENERATE PRINT FILE BY PERFORMING NON-ORTHOGONAL INTERLACING OF SELECTED FRAMES ON A PIXEL-BY-PIXEL BASIS USING PIXEL MATRIX (OR MAPPING OF PIXELS)
1240
WITH DIGITAL PRINT FILE, OPERATE OUTPUT DEVICE TO PRINT INTERLACED IMAGE
1250
OPTIONALLY, PERFORM ADDITIONAL ASSEMBLY STEPS TO FABRICATE LENTICULAR PRODUCT
1260
END
1290

FIG.12

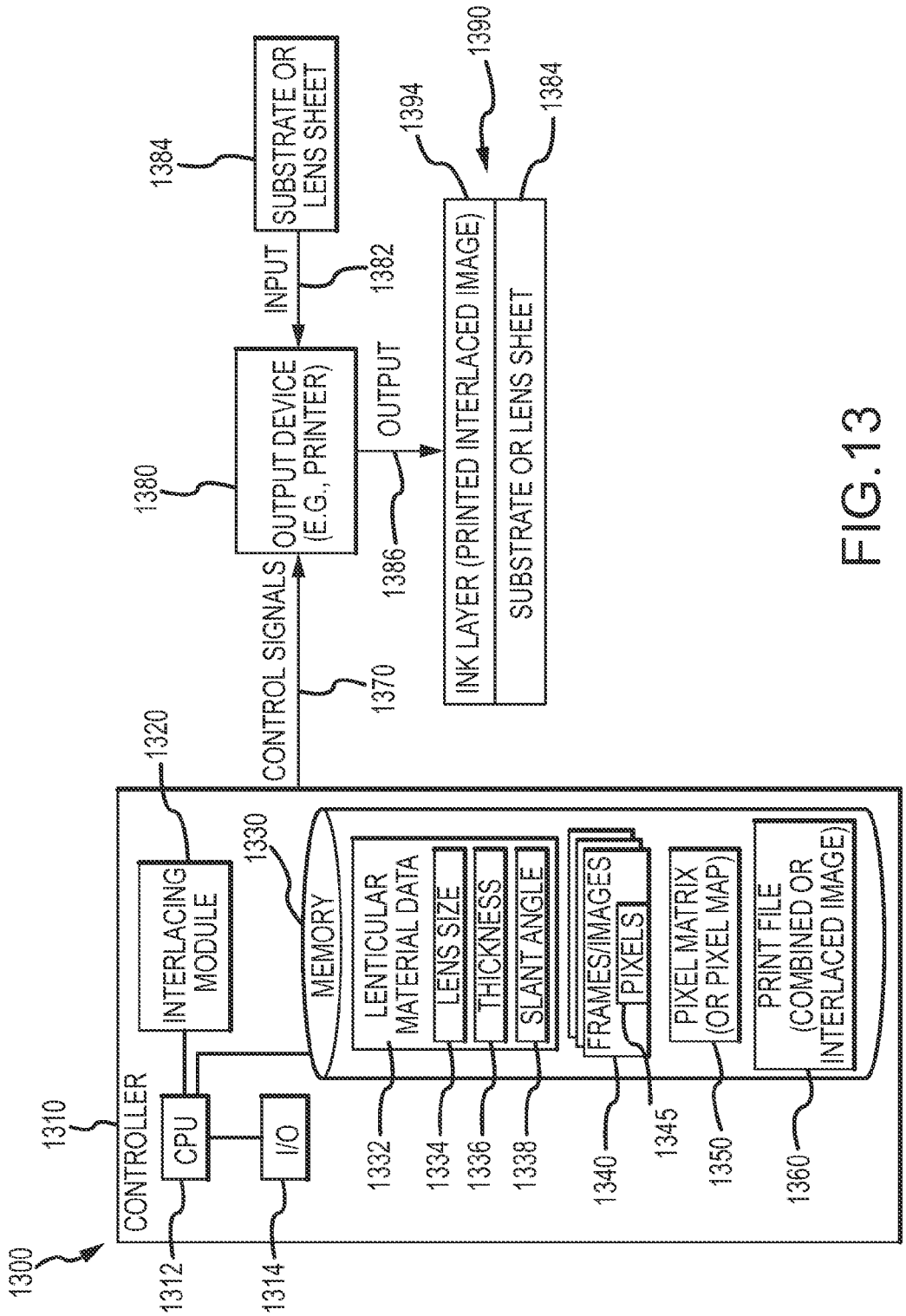
1300
1310
CONTROLLER
CPU
I/O
1312
1314
1320
INTERLACING MODULE
1330
MEMORY
LENTICULAR MATERIAL DATA
LENS SIZE
THICKNESS
SLANT ANGLE
FRAMES/IMAGES
PIXELS
PIXEL MATRIX (OR PIXEL MAP)
PRINT FILE (COMBINED OR INTERLACED IMAGE)
1332
1334
1336
1338
1340
1345
1350
1360
CONTROL SIGNALS
1370
1380
OUTPUT DEVICE (E.G., PRINTER)
OUTPUT
1386
INPUT
1382
1384
SUBSTRATE OR LENS SHEET
1394
1390
INK LAYER (PRINTED INTERLACED IMAGE)
SUBSTRATE OR LENS SHEET
1384

FIG. 13

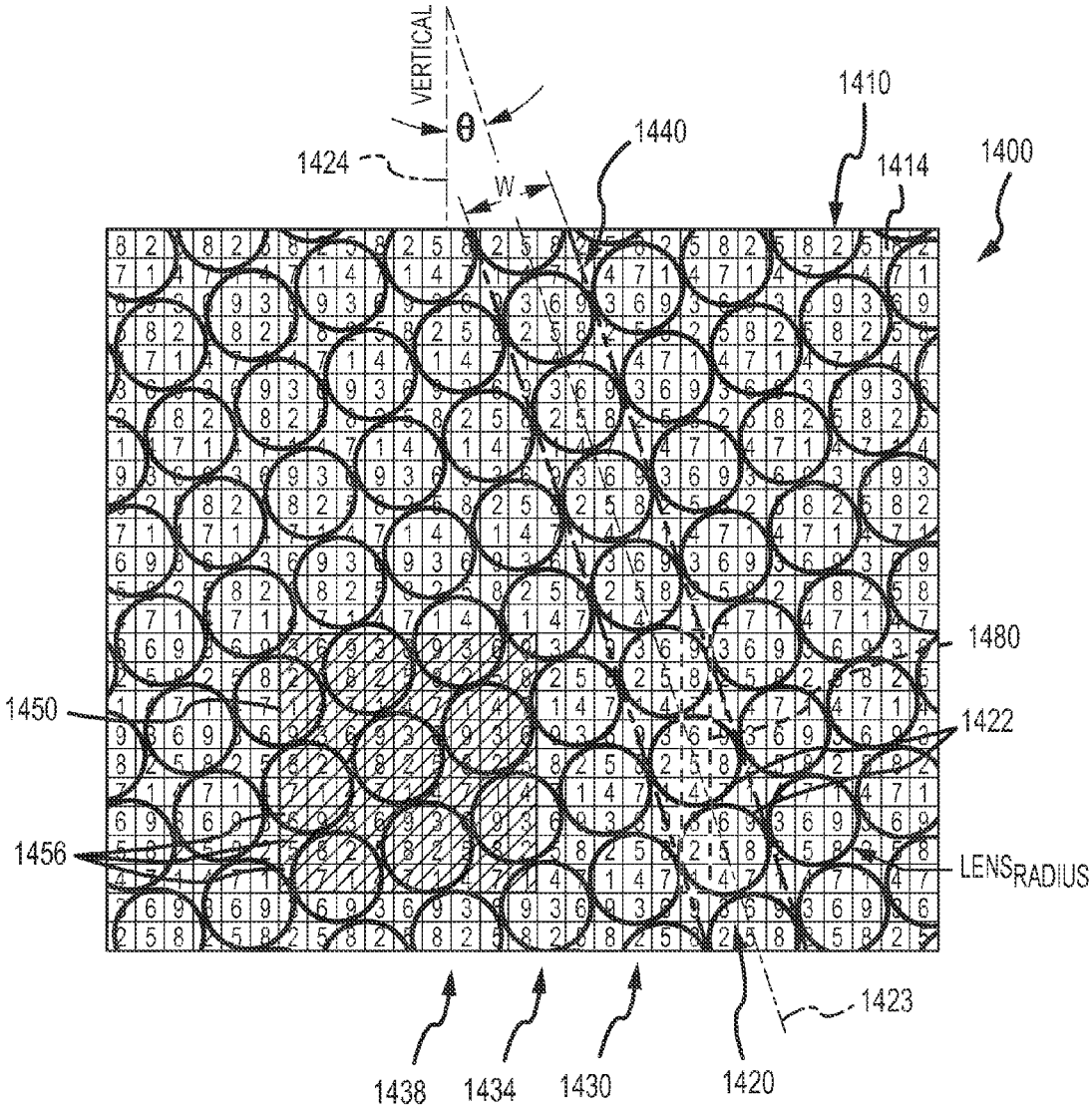
VERTICAL
θ
1424
W
1440
1410
1414
1400
1480
1450
1422
1456
LENS RADIUS
1423
1438
1434
1430
1420

FIG.14

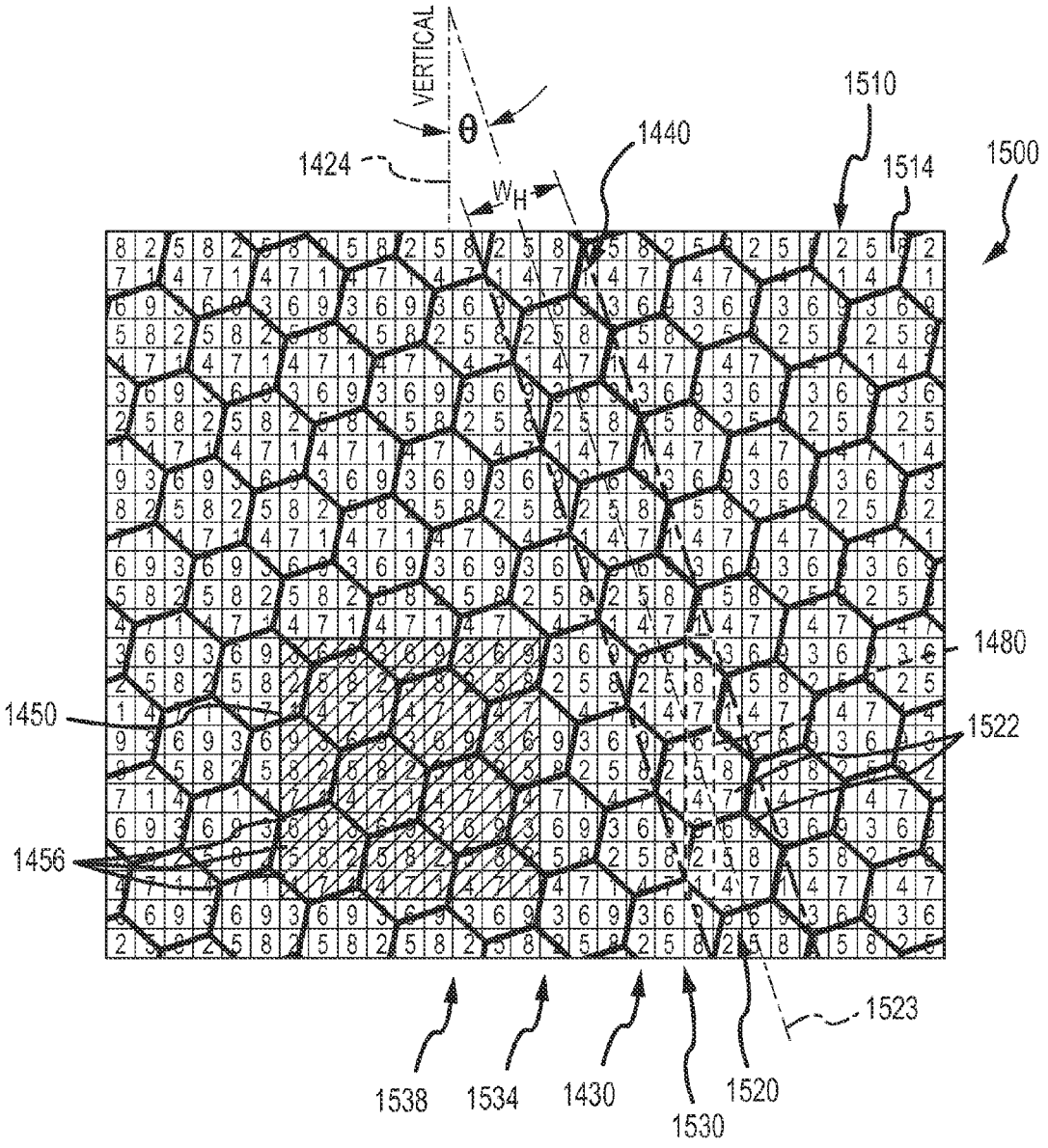
VERTICAL
θ
1424
W_H
1440
1510
1514
1500
1480
1450
1522
1456
1523
1538
1534
1430
1530
1520

FIG.15

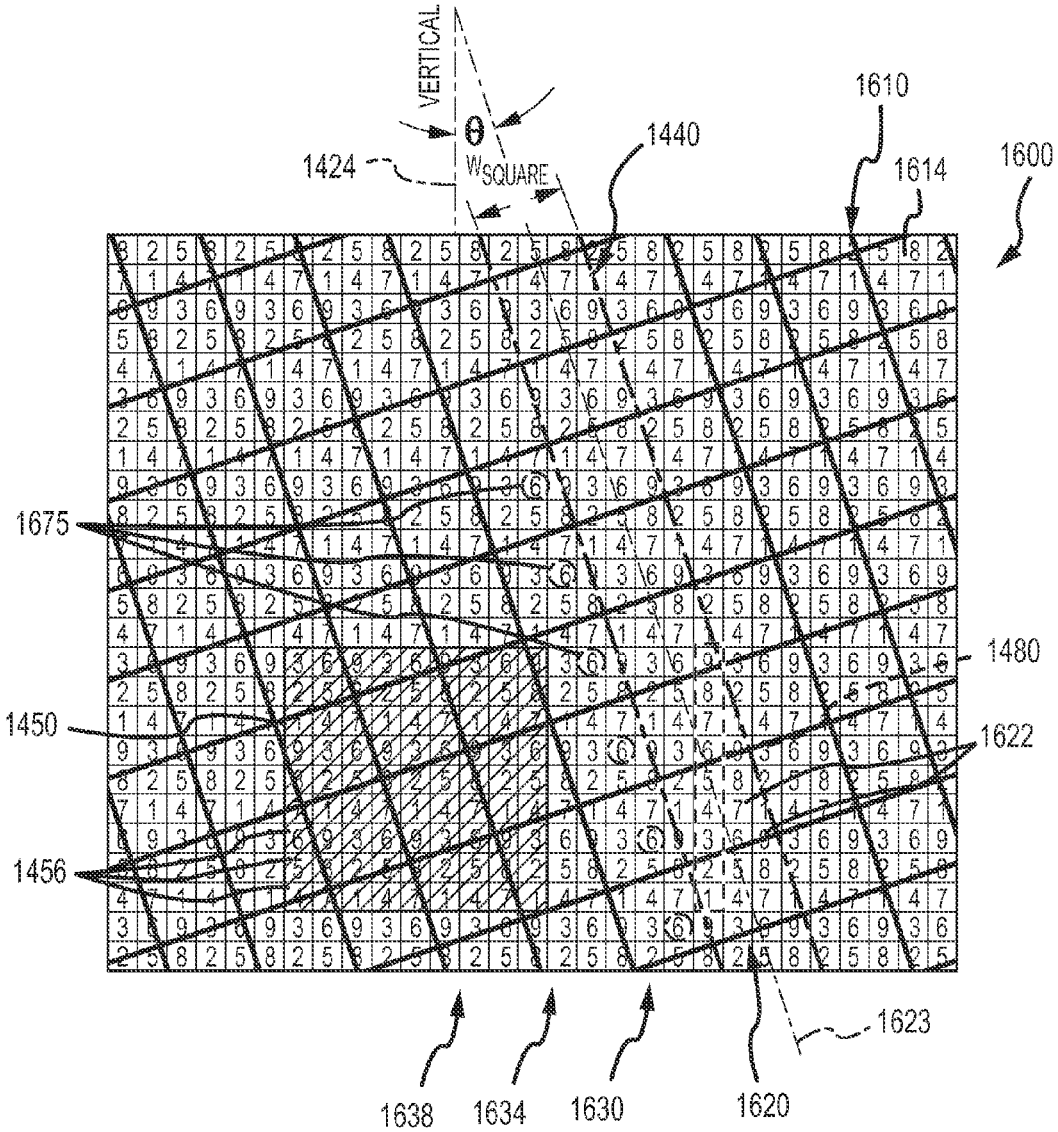
VERTICAL
θ
W SQUARE
1424
1440
1610
1614
1600
1675
1480
1450
1622
1456
1623
1638
1634
1630
1620

FIG.16

SLANT LENS INTERLACING WITH LINEARLY ARRANGED SETS OF LENSES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/282,271, filed May 20, 2014, which is a continuation-in-part of U.S. patent application Ser. No. 14/088,519, filed Nov. 25, 2013, which claims the benefit of U.S. Provisional Application No. 61/797,145, filed Nov. 30, 2012, all of which are incorporated herein by reference in their entireties.

BACKGROUND

1. Field of the Description

This description is generally directed toward methods of interlacing images for use in printing images viewable through a lenticular lens array or lens sheet, and, more particularly, to methods of interlacing to provide an increased amount of information (e.g., interlaced images or frames) underneath each lenticule to facilitate use of thinner lens sheets.

2. Relevant Background

Elaborate graphics or visual displays can be produced through the use of sheets of lenticular lens arrays as these arrays of lenses can be combined with printed interlaced images to provide three-dimensional (3D) and animated imagery. For example, lenticular lens material is used in the packaging industry for creating promotional material with appealing graphics and typically involves producing a sheet of lenticular lens material and adhesively attaching the lenticular lens material to a separately produced object for display. The production of lenticular lenses is well known and described in detail in a number of U.S. patents, including U.S. Pat. No. 5,967,032 to Bravenec et al. and U.S. Pat. No. 6,781,761 to Raymond.

In general, the production process includes selecting segments from visual images to create a desired visual effect, slicing each segment into a predefined number of slices or elements (such as 10 to 30 or more slices per segment), and interlacing the segments and their slices (i.e., planning the layout of the numerous images). Lenticular lenses or lens sheets are then fabricated according to the number of slices or the interlacing may be performed to suit the lens sheets, e.g., to suit a particular lenticules or lenses per inch (LPI) of the lens sheet. The lenticular lenses generally include a transparent web that has a flat side or layer and a side with optical ridges and grooves formed by linear or elongated lenticules (i.e., lenses) arranged side-by-side with the lenticules or optical ridges extending parallel to each other over the length of the transparent web. To provide the unique visual effects, ink (e.g., four color ink) is applied to or printed directly on the flat side of the transparent web to form a thin ink layer (or a printed image is applied with adhesive to the back or planar side of the transparent web), which is then viewable through the transparent web of optical ridges.

Each lenticule or lens of the lenticular layer is paired or mapped to a set or number of the interlaced image slices or elements. Generally, only one of the slices is visible through the lenticule at a time based on the position of the lenticule relative to a viewer's eye. In other words, the animation, 3D, or other graphic effect is achieved by moving the lenticule or the viewer's position to sequentially view each of the interlaced image slices under the lenticule and allow a viewer to see each segment of the image by combining the slices viewed from all the lenticules.

In producing conventional lenticular lens material, it is desirable to use as little material as possible, i.e., to produce effective lenticules or lenticular lens arrays with as thin web material as possible. Decreasing lens thickness is also desirable to facilitate fabrication using techniques such as web printing that are very difficult or impractical with thicker lens materials. Thin lenticular lens material is desired to save on material costs and to provide a relatively flexible lens material or substrate that can be easily applied to products and product containers, such as in a label that can be attached to a box or to a bottle as part of a wraparound label or on a cup to provide desirable visual effects. To make lenticular lens materials thinner, the whole structure must be properly scaled downward together. In other words, the lenticules and the printed interlaced image must be shrunk or made smaller together to allow proper mapping of the image slices to the lenticules.

However, such shrinking of the lenticules has proven very difficult with limitations associated with printing the interlaced images often preventing the lens layer or web from being made very thin. As noted above, all the interlaced slices for each segment are placed underneath a single lenticule such that numerous slices have to be printed with very little width to be mapped to the lenticules width or pitch. With coarser lens arrays (i.e., with lower the frequency or LPI), the printing can be accomplished more easily and mapping to lenticules of the image slices achieved more accurately. However, coarser lens arrays with frequencies of 10 to 30 LPI tend to be very thick because general physics or optical rules for focusing with conventional lenticular material require that more lens thickness or more lens material be provided to achieve effective focusing. For example, a 15 LPI lenticular lens array with a fairly common viewing angle (such as a 22-degree viewing angle) may be mapped to an interlaced image that is printed or provided directly behind the lenticular lens array, with each of the lenticules in the lens array being mapped to or paired with all image slices of a paired segment of the interlaced image. If the lens array is formed from acrylic, the lens array would need to be about ⅜-inch thick to enable the lenticules to properly focus on the paired image slices.

Traditionally, lenticular printing has been a multi-step process that includes creating a lenticular image from at least two images and combining it with a lenticular lens. The lenticular printing process can be used to create various frames of animation for a motion effect, can be used for offsetting the various layers at different increments for a 3D effect, or can be used simply to show a set of alternate images that may appear to transform into each other. Once the various images are collected, they are flattened into individual, different frame files, and, then, the frame files are digitally combined into a single final file for use in printing an interlaced image. The digital combining process is often called "interlacing."

Once the combined or interlaced file is generated, it can be used to print an interlaced image directly to the back (or smooth/planar) side of the lenticular lens sheet. In other applications, the interlaced image may be printed onto a substrate (e.g., a synthetic paper or the like), which is then laminated onto the lens (e.g., a transparent adhesive may be used to attach the substrate with the printed interlaced image onto the lenticular lens sheet). When printing to the backside of the lens sheet, the registration of the thin slices or elongated interlaced images to the lenses is important during

the lithographic or screen printing process to avoid or at least limit ghosting or other effects that produce poor imagery.

With traditional lenticular interlacing, each image is arranged or sliced into strips, which are then interlaced with one or more similarly arranged or sliced images such as by splicing or interlacing. The end result is that a person's single eye looking at the printed interlaced image through the lenticular lens array (or lens sheet) sees a single whole image while a person's two eyes may see different images (e.g., right and left-eye images), which provides a desired autostereoscopic or 3D perception.

The process of creating strips of information from graphics or images and then scrambling them into a single image for printing underneath a lens sheet can be problematic. One significant problem is that there is a limitation on the amount of information (e.g., pixels) that can be placed underneath each lenticule or elongated lens in the lens sheet. For example, a lens or lenticule has a particular size (e.g., a width set by the LPI of the lens sheet or lens array), and the printer used to provide the printed interlaced image may have a particular resolution (e.g., dots per inch (DPI)). Hence, these limitations or parameters of a lenticular product or assembly (e.g., a security stamp or security thread for a bank note or piece of currency) define the maximum number of frames or images that can be interlaced and then printed on a lens sheet by the equation: Maximum number of frames=DPI/LPI.

FIG. **1** illustrates a cross-sectional view (or end view) of a very simple lenticular device or assembly **100** that is useful for discussing these limitations associated with traditional lenticular printing and interlacing. As shown, the assembly **100** includes a single lenticule or elongated lens **110** with a planar side or base **112** of a particular width, L_W (lenticule size as defined by the LPI of a sheet including lens/lenticule **110**). An ink layer or printed interlaced image **120** is provided directly onto the back side or base **112** of the lenticule **110**, and, in this example, the interlaced image **120** includes five image slices **124** (e.g., long, thin portions of five different images/frames) that would extend the length of the lenticule **110** in a parallel manner (parallel to each other and to the longitudinal axis of the lenticule/lens **110**).

In the assembly or device **100**, the lens size, L_W, and pixel size is such that the lens **110** can only work well with a maximum of five interlaces or image slices **124** (e.g., five pixels with each pixel being associated with one of the five interlaced frames/images). These are shown to be exactly aligned with the lens **110** but may, in practice, be somewhat offset while still being parallel to the longitudinal axis of the lens **110** and still achieve a desirable image when viewed through the lens **110**. The interlacing is orthogonal in that the five pixels extend orthogonally across the lens **110** relative to its longitudinal axes (e.g., the elongated slices of the image extend parallel to the longitudinal axis of the lens **110** such that side-by-side pixels associated with these slices/interlaces extend across the lens width, L_W).

However, in order to achieve a 3D effect with lenticular sheets, the minimum number of frames needed is six or more images/frames. This means, for example, that for a 1200 DPI output device (e.g., printer) the lenticular lenses must have a width associated with a 200 LPI or higher (where LPI=DPI/Number of frames or, in this case, 200 LPI=1200 DPI/6 frames). This relationship between resolution of the output device, the number of frames needed to produce 3D, and the lens size creates a significant restriction to developing thinner lenticules and corresponding thinner lenticular products (such as security threads or stamps for currency or bank notes). However, it should be understood that the limitation is not the ability to fabricate thinner lens sheets because lens sheets that are very thin can readily be produced with presently available technology. Instead, the restriction or challenge to providing thin lens sheets comes from the high resolution that would be required, and, therefore, the limitation of the number of frames that can be printed on or underneath smaller sized lenses (e.g., lenses with smaller widths or L_W).

FIG. **2** illustrates a top perspective view of a lenticular product or assembly **200** that may use conventional or traditional interlacing. As shown, the assembly **200** includes a lens sheet or lens array **210** that may be formed of a thickness of plastic or other transparent material. On a top or exposed side, the lens sheet **210** is grooved or shaped to provide a number of lenticules or elongated lenses **214** that extend in a parallel manner from one end to the other of the sheet **210**. As is common, the lenticules **214** extend "vertically" in the array or sheet **210** or with their longitudinal axes being orthogonal to the top and bottom edges **211**, **213** of the sheet **210** (or being parallel to left and right side edges). Each lenticule or lens **214** has a size or width, L_W, that is defined by the LPI of the lens sheet **210**.

In the lenticular assembly **200**, an ink layer **220** is printed directly upon a planar back side or bottom side **216** of the lens sheet **210** (or may be provided on a substrate that is laminated onto the lens sheet **210**). The ink layer **220** is printed to provide a number of interlaced images or slices **224** underneath each lenticule **214** such as to provide a 3D effect. As shown, the interlaced image of ink layer **220** has five slices **224** associated with five different frames underneath each lenticule **214**, with different slices of the same frame being provided under different lenticules **214** in the sheet **210**. In this case, the image file for printed ink layer **220** was created with five pixels to match the size, L_W, of each lens **214**.

Lenticular devices may also use lenses or lenticules that are provided in a sheet or array with an angular arrangement, e.g., not parallel or orthogonal to edges of the sheet/array. FIG. **3** illustrates a conventional slant lens lenticular device or assembly **300** in which a lens or lenticular sheet **310** is combined with an interlaced image provided in an ink layer **320**. The lens sheet **310** includes a number of lenticules or lenses **314** on a top or exposed side, and the lenticules **314** extend parallel to each other but, in this lens sheet **310**, the lenticules **314** are not arranged vertically or horizontally. In other words, the lenticules or lenses **314** are "slanted" with their longitudinal axes, $Axis_{Long}$, as shown at **315** arranged to each be at a particular angle, θ, relative to a side edge **311** of the lens sheet **310**, with the slant angle, θ, being less than 90 degrees (not orthogonal) such as 20 to 60 degrees or the like. Again, each lens **310** has a size or width, L_W, set by the LPI of the sheet **310** that may limit the number of image slices that may be placed underneath each of the lenses **314** with conventional interlacing techniques.

The lenticular assembly **300** further includes an ink layer **320** providing a printed interlaced image with a number (here five) of slices **324** provided under each lens **314**. In other words, instead of having the interlaces or slices **324** provided with "vertical" strips that are spliced together, the ink layer **320** provides the image with slanted strips **324** matching the slant angle, θ, of the lenses **314**. Hence, the interlacing for slant lens sheets such as sheet **310** has traditionally involved arranging the elongated slices of a number of images to extend parallel to each other and also to the longitudinal axis, $Axis_{Long}$, as shown at **315** of the lenses **314**. Hence, the interlacing of the device **300** again is to match the size of the lenses **314** with five pixels arranged

orthogonally to the longitudinal axis, $Axis_{Long}$ (e.g., to extend across the width, L_W, of the lens **314**). As can be seen, the use of slant lens does not increase the amount of information provided under the lens array when traditional interlacing is used to generate the interlaced image.

There remains a need for methods for providing an interlaced image (i.e., interlacing methods) that allow additional information to be provided under the lenses or lenticules of a sheet of lenticular material (or a lens sheet). Preferably, such interlacing methods would be useful with existing and to-be-built output devices (e.g., printers) to allow lenticular products to be provided with desirable imagery (e.g., 3D imagery) with much lower thicknesses of lenticular material or lens sheets, e.g., to support use of lenticular assemblies or elements as security threads, stamps, and the like in bank notes, currency, and other items.

SUMMARY

The inventors recognized that thinner lenses and, therefore, thinner lenticular material could be used to display 3D and other imagery by printing more information under each lens or lenticule. To this end, an interlacing method was developed for use with angled lenticules or slant lenses that differs from traditional interlacing, in part, by utilizing non-orthogonal interlacing.

Interlacing of images into a combined image file (or interlaced print file for controlling an output device or printer) involves arranging a set of pixels in a line or column that is transverse but non-orthogonal to the longitudinal axis of a slant lens or slanted lenticule. Each of these pixels is associated with a different frame/image, e.g., 6 or more frames are typically used in each interlaced image, with one being visible through the lens or lenticule at a time by a viewer. The new slant lens interlacing method does not involve slicing each frame and then splicing these slices together. Instead, individual pixels from each frame are combined within a digital print file in a unique pattern to provide the non-orthogonal interlacing described herein (e.g., the new interlacing may be considered "matrix interlacing" or "angular-offset interlacing").

By utilizing non-orthogonal interlacing or matrix interlacing to create a print file that is used to control an output device/printer, a significantly larger amount of information may be presented under each slant lens or slanted lenticule. For example, the traditional interlacing example provided in FIG. **3** was able to provide five pixels under each lenticule while the new interlacing process is able to provide 10 to 14 pixels under the same-sized lenticule.

More particularly, a method is provided for generating an interlaced print file for use in printing on or for a lens sheet with slanted lenticules. The method includes providing digital files for a set of frames for interlacing and inputting a slant angle for lenticules of the lens sheet. The method further includes interlacing the frames to form an interlaced print file by positioning a number of pixels from each of the frames in the print file based on a pattern of pixel locations provided in a predefined pixel matrix. The pixel matrix is configured to map the plurality of pixels to the lenticules of the lens sheet based on the slant angle. To this end, interlacing of the frames is non-orthogonal to a longitudinal axis of each of the lenticules (i.e., not directly across the width of each lens as in traditional slant lens interlacing).

In some implementations of the method, each set of interlaced ones of the pixels associated with the set of frames is aligned in a column or in a row of the pixel matrix (e.g., interlacing is along a vertical line/column (or horizontal line/row) while the lenses are slanted from vertical (or from horizontal)). The pixel matrix may be made up of a number of spaced apart sets of the pixels from each of the frames with the pixel locations for each of the spaced apart sets being arranged linearly at an offset angle of about the slant angle. In such cases, the slant angle may be in the range of 14 to 15 degrees, in the range of 18 to 19 degrees, in the range of 26 to 27 degrees, or in the range of 44 to 46 degrees. The number of frames in the set of frames may vary with some embodiments interlacing 6 frames, 9 frames, or 16 frames to create a desired effect (e.g., 3D imagery visible through a lens sheet). In these cases, the pixel matrix comprises a repeating 6 by 6 pixel matrix, a 9 by 9 pixel matrix, or a 16 by 16 pixel matrix.

According to another aspect of the present description, a lenticular product is provided that includes a transparent lens sheet and an image or ink layer. The lens sheet includes a first side having a plurality of side-by-side, elongated lenses each at an angle in the range of 10 to 46 degrees from a vertical or a horizontal axis of the lens sheet. The ink layer is proximate to a second side of the lens sheet opposite the first side (e.g., is printed onto this planar side or is laminated to the side with transparent adhesive). The ink layer includes pixels from a plurality of digital images, with the pixels being arranged in a pattern of pixel locations providing non-orthogonal interlacing of the digital images relative to each of the elongated lenses. The pattern of pixel locations can be adapted to align a number of the pixels from each of the digital images to be parallel to a longitudinal axis of an adjacent one of the elongated lenses such that pixels of only one digital image are viewed at a time through the lens sheet's lenses.

In some cases, the lens sheet has a thickness in the range of 10 to 2500 microns and the elongated lenses are provided on the first side at 75 to 1500 LPI (which defines the width or size of each lens). The plurality of digital images may include a number of images selected from the range of 6 images to 16 images, and, further, the non-orthogonal interlacing may be provided by sets of the pixels equal in number to the number of images including at least one pixel from each of the plurality of digital images. It may be useful for the sets of the pixels that are providing the non-orthogonal interlacing to be aligned in a row or in a column of the pattern of pixel locations.

In particular implementations of the lenticular product, the angle of the elongated lenses is 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees. The plurality of digital images can be selected such that the plurality of pixels in the ink layer produces a 3D image when viewed through the elongated lenses of the lens sheet. A transparent adhesive may be provided to attach the ink layer that is printed on a substrate onto the lens sheet or to attach the lens sheet and ink layer to a substrate. The lenticular product may be nearly any object such as a piece of paper or polymer currency (or bank note) with a security thread or stamp (e.g., a 3D image is visible with the security thread or stamp using slant lenses combined with the interlacing taught herein).

According to yet another aspect of the present description, a method is provided for fabricating a lenticular product. The method includes providing a pixel matrix defining a plurality of pixel locations for pixels of a number of images. The pixel locations are adapted to position the pixels associated with each of the images in a line parallel to longitudinal axes of lenticules provided at a slant angle in a lens sheet. The pixel locations of the matrix are further adapted to interlace sets of the pixels associated with differing ones

of the images along an interlace line that is transverse to and non-orthogonal to the longitudinal axes of the lenticules.

The method further includes generating a digital print file by interlacing the images according to the pixel matrix by placing the pixels of the images into the pixel locations identified in the pixel matrix. Then, with the digital print file, the method includes operating an output device to print an interlaced image onto a planar back side of the lens sheet or onto a substrate for later application to the back side of the lens sheet. In some preferred embodiments, the slant angle is 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees. In these and other embodiments, the lenticules can be provided on the lens sheet at an LPI of at least 75 LPI, and the lens sheet may have a thickness of 10 to 2500 microns.

According to a further aspect of the present description, an optical product or assembly is provided that includes a transparent lens sheet. This sheet or lens material has a first side with a plurality of side-by-side sets of linearly arranged lenses. Each set is at a slant angle in the range of 10 to 46 degrees from a vertical or a horizontal axis of the lens sheet. The product or assembly further includes an ink or image layer, proximate to a second side of the lens sheet opposite the first side, that includes pixels from a plurality of digital images or frames. The pixels are arranged in a pattern of pixel locations providing non-orthogonal interlacing of the digital images relative to each of the sets of the linearly arranged lenses. The pattern of pixel locations is adapted to align a number of the pixels from each of the digital images to be parallel to a line extending through a center of the linearly arranged lenses in an adjacent one of the sets of the linearly arranged lenses.

In some preferred embodiments, each of the linearly arranged lenses has a round base while in others each of the linearly arranged lenses has a hexagonal base or a square base. In some cases, the lens sheet has a thickness in the range of 10 to 2500 microns and the sets of the linearly arranged lenses are provided on the first side at 75 to 1500 LPI. Further, each of the linearly arranged lenses has a size parameter matching an LPI of the sets of the linearly arranged lenses (e.g., a width of a square or hexagonal lens or a diameter of a round lens may be chosen to match the LPI (e.g., a corresponding width of a lenticule provided at such an LPI)).

In many cases, the plurality of digital images includes a number of images selected from the range of 5 images to 16 images, and the non-orthogonal interlacing is provided by sets of the pixels equal in number to the number of images including at least one pixel from each of the plurality of digital images. In these cases, the sets of the pixels providing the non-orthogonal interlacing are aligned in a row or in a column of the pattern of pixel locations. Further, it is sometimes useful for the slant angle to be within a range of 14 to 15 degrees, a range of 18 to 19 degrees, a range of 26 to 27 degrees, or a range of 44 to 46 or more specifically for the slant angle to be 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-section of a simple lenticular device or assembly illustrating conventional interlacing;

FIG. **2** illustrates a top perspective view of a conventional lenticular device or product;

FIG. **3** illustrates a top perspective view similar to FIG. **2** showing a second conventional lenticular device or product that uses slant lens with conventional orthogonal interlacing;

FIG. **4** is a diagram illustrating use of new non-orthogonal interlacing (matrix interlacing) to take advantage of a greater amount of printing space under a slant lens or slanted lenticule;

FIG. **5** is a diagram of traditional interlacing and an example of non-orthogonal or matrix interlacing as taught herein, with both being used with a slant lens;

FIGS. **6-9** each illustrate a diagram of an exemplary step of non-orthogonal interlacing that may be used in generating a pixel map for creating a digital print file;

FIG. **10** illustrates a pixel map or matrix of pixels arranged in a pattern useful for interlacing nine frames or images to provide the 18.435 degree, non-orthogonal configuration discussed with reference to FIG. **7**;

FIGS. **11A-11C** illustrate, schematically, end views of lenticular products or assemblies that may be fabricated using the non-orthogonal interlacing or matrix interlacing taught herein;

FIG. **12** illustrates a flow diagram of a method of fabricating a lenticular produce assembly combining slant lens material with an image printed according with the non-traditional interlacing taught herein;

FIG. **13** illustrates a functional block diagram of a system for printing a non-orthogonally interlaced image for use with slanted lenticules (e.g., with lenticular material with slanted lenses);

FIG. **14** illustrates an optical product with a lens sheet having lenses with round-shaped bases (or round lenses) arranged in linear sets arranged at slant angles for use with an image or ink layer printed using a pixel map or matrix of pixels (such as the pixel map of FIG. **10**);

FIG. **15** illustrates an optical product, similar to that shown in FIG. **14**, with a lens sheet having lenses with hexagonal-shaped bases (or hexagonal lenses); and

FIG. **16** illustrates an optical product, similar to that shown in FIG. **14**, with a lens sheet having lenses with square-shaped bases (or square lenses).

DETAILED DESCRIPTION

Briefly, the present description is directed toward a method for lenticular interlacing for use with lens sheets or lenticular material having slanted lenticules or slant lenses (slant lens interlacing, matrix interlacing, and non-orthogonal interlacing, interchangeably). The interlacing differs from traditional interlacing because it does not simply involve providing slices of an image (or pixels associated with each) orthogonally or directly across the width of the lens (or with slices arranged in parallel at an angle matching the lens). Instead, each frame or image is first considered as a set of pixels, and pixels from each frame or image are arranged in a matrix or pattern such that a set of pixels made up of a pixel from each frame is arranged transverse but non-orthogonally under the lenticule. In this way, a much larger number of pixels for a particular output device resolution (DPI) can be provided under a lenticule for selective viewing. As a result, the non-orthogonal interlacing supports use of a thinner lens sheet to achieve a particular imagery or supports a much better quality imagery to be viewed with a predefined lens sheet thickness.

In FIG. **3**, the image provided in the print layer **320** with interlaces/slices **324** is basically the same as the image provided with print layer **220** in FIG. **2**. Particularly, the interlaces/slices **324** are arranged with the same angle as the lenses **314**, and the amount of information or frames is also limited by the same relationship between the lenses, DPI, and resolution. In order to break this relationship (i.e.,

frames multiplied by LPI equals DPI) that limits the amount of information or, in this case, pixels that can be printed under the lenses, the inventors recognized that it would be useful to use a completely different pixel array (or pixel map) for interlacing the images/frames under the slant lens.

FIG. **4** provides a diagram of a single slant lens or slanted lenticule **400** for which it may be desirable to generate a print file for use in printing an interlaced image. The lenticule **400** is shown to be angled (not simply vertical or horizontal on a surface of a lens sheet) with its longitudinal axis, $Axis_{Long}$, as shown at **405** being at an offset or slant angle, θ, to vertical (or horizontal) as shown at **407** (e.g., a side of a lens sheet or the like). Traditional interlacing would be provided with the slant lens **400** by arranging slices parallel to the axis **405** of the lens **400**, which would provide a number of pixels orthogonally across the lens **400** or to fill the dimension, L_W (e.g., the width or size of the lens **400** as defined by its LPI). In contrast, the non-orthogonal interlacing of the present description calls for providing a number of interlaced pixels transverse to the longitudinal axis **405** but not orthogonally, i.e., along the line **420** which has a length or dimension, $D_{Interlacing}$, that is much larger than the width, L_W, of the lens **400**.

In a slant lens **400** as shown in FIG. **4**, there is a triangle with properties that can be used to fit more information under the lens **400**. The slant lens **400** is defined by a size, L_W, as shown by line **428**, which is given by: L_W=1/LPI. If, for example, a lens sheet is fabricated at 75 LPI, the size, L_W, of each lenticule or lens **400** would be 1/75 inches or 0.0133 inches. However, the vertical distance, $D_{Interlacing}$, as shown with line **420** (or the hypotenuse of the triangle) is larger than the lens size, L_W, and this magnitude of this vertical distance, $D_{Interlacing}$, is defined or given by the triangle that is formed and shown in FIG. **4**. Specifically, the triangle formed by or made up of a segment/length of the lens **400** as shown by line **424**, the width of the lens **400** as shown by line **428** (which is orthogonal to the longitudinal axis **405** of the lens **400**), and the vertical distance, $D_{Interlacing}$, as shown by line **420** contains an angle, a, (between lines **420** and **424**). This triangle may be defined by the equation: $D_{Interlacing}=L_W/\sin(a)$. In turn, this equation may be rewritten as: $D_{Interlacing}=(1/LPI)/\sin(a)$.

Using specific values may be illustrative at this point in the description. For example, a lenticular array may be formed at 75 LPI, which provides a lens size or width, L_W, of 0.0133 inches. If the angle, a, is taken to be 25 degrees (as one useful, but non-limiting example), the vertical distance, $D_{Interlacing}$, is 0.0315 inches, which is nearly three times the lens width, L_W. Hence, one can readily appreciate why it is desirable to provide the interlacing or interlaced pixels along the line **420** rather than along the orthogonal or line **428**. Using the larger distance, $D_{Interlacing}$, to arrange the pixels in a vertical position with a slanted lens **400** provides much more room or printing space than going with the traditional interlacing across the lens **400**.

However, it was also understood by the inventors that traditional interlacing techniques could not be used to provide information under the line **420** to allow viewing of a quality image such as 3D imagery with 6 or more interlaced frames/images. Instead, FIG. **5** illustrates a diagram **500** comparing traditional interlacing with a new non-orthogonal or matrix interlacing process to place pixels or information under this vertical distance or the hypotenuse of the triangle discussed with reference to FIG. **4**.

As shown, a slant lens **510** is provided as may be included in a lens sheet or piece of lenticular material in a lenticular device/assembly (such as a security thread or stamp for currency or bank notes or other items). Traditional interlacing is shown with the set of pixels **520** extending side-by-side orthogonally across the lens **510**. The size, L_W, of the lens **510** limits the number of pixels **520** with five pixels being shown in this example.

In contrast, though, non-orthogonal or matrix interlacing is shown with the set of pixels **530** extending transverse but non-orthogonally across the longitudinal axis of the lens **510**. Specifically, the pixel set (or interlace set) **530** is made up of a number of side-by-side pixels **531**, **532**, **533**, **534**, **535**, **536**, **537**, **538**, **539**, **540**, **541** from a like number of frames or images being interlaced/combined to produce imagery viewable via lens **510**. In this example, the pixels of each of the sets **520** and **530** are of the same size but there is room along the vertical or hypotenuse for a greater number of such pixels (e.g., 5 pixels in the traditional interlacing set **520** compared with 12 pixels in the non-orthogonal interlacing set **530**, which is more than a doubling of the number of pixels or amount of information that can be printed under or provided under the slant lens **510**). The dashed box **590** is useful for highlighting or showing an exemplary lens focus for the lens **510**, which shows that with the new interlacing **530** (and a number of other interlacing sets similar to set **530**) the lens **510** is still focusing on pixels **539**, **549**, **559**, **569** that belong to or are associated with a single frame or image.

The diagram **500** of FIG. **5** and the illustrated ideal or goal interlacing **530** is useful for demonstrating that the use of non-orthogonal interlacing would be desirable for increasing the amount of information that can be placed under a slant lens **510**. However, a limitation facing those skilled in the art trying to fabricate a slant lens lenticular device is how to work with printing limitations of output devices or printers used to provide or print the interlaced image (e.g., provide the ink layer underneath a lens sheet). With this problem in mind, the inventors recognized that it would be desirable to provide a matrix of pixels or a pixel map that can be used to generate a print file for controlling a printer/output device. In other words, each image or frame may be first stored digitally as a set of pixels, and pixels from each frame may be arranged or combined (interlaced) according to a predefined matrix of pixels or pixel map to achieve a print file with non-orthogonal interlacing suited for a particular slanted lenticular material (e.g., a transparent lens sheet with lenses slanted from vertical/horizontal at a particular or predefined angle).

FIG. **6** illustrates a diagram or schematic **600** of a step in a non-orthogonal interlacing process that may be carried out to generate a pixel map for creating a digital print file from a set of frames or images (e.g., 6 or more frames used in creating a 3D graphic under slant lens lenticular material). A first frame or image may be chosen for processing, and this image/frame may be pixilated or separated into individual pixels of a certain size and location (X, Y coordinates) within the image/frame. Then, as shown in FIG. **6**, a blank pixel map **610** is provided made up of rows and columns of pixels **612** (or pixel locations for receiving or being assigned pixels from the interlaced images). Then, as shown in FIG. **6**, a string or line **620** of pixels **624** from a single frame/image of the set of frames/images to be interlaced/combined are positioned in the pixel map **610** at locations/coordinates **612** to follow a particular angle, a, which is measured as shown between a longitudinal axis (or edge) of a slant lens and a vertical line (which defines the interlacing distance, $D_{Interlacing}$, for the slant lens).

Due to the rigidity of the pixel map **610** with its orthogonal rows and columns of pixel locations **612**, the inventors

understood that it is preferable to map the pixels **624** of string/line **620** to follow a predefined angular offset. Here, angle, a, is 26.57 degrees (e.g., 20 to 30 degrees) as the pixels **624** are arranged in a pattern to define a line or string **620** (shown to be linear with dashed line **621**) that will be concurrently visible through a slant lens with a similar angular offset (e.g., from vertical or horizontal in the lens sheet).

In practice, the mapping **610** is created by placing a first pixel **624** and then placing a next pixel at the desired angular offset (e.g., vertically down two pixel locations **612** in the same column and over one pixel location **612** to an adjacent row when starting in an upper "left" position), and then repeating this process to the end/edge of the pixel map **610**. In this example, since sin 26.57 degrees=0.4226, the interlacing distance, $D_{Interlacing}$ as shown in FIG. **4** is given by $D_{Interlacing}=L_W/\sin a$ or $L_W/0.4226$. This provides about double the space to print frames (pixels associated with frames) with the same lens size, L_W, and with the same resolution.

In FIG. **7**, a blank pixel map **610** again may be provided with a plurality of rows and columns of pixel locations (for pixels of a particular size to suit an output device resolution or the like). Diagram **700** shows a step of a non-orthogonal interlacing being performed to create a pixel map for a slant lens with an angular offset of 18.435 degrees (e.g., slant angle, a, is in the range of 15 and 20 degrees with about 18.5 degrees being more ideal). As shown, pixels **724** of a single frame/image of a set of frames/images being combined/interlaced are arranged as shown in a pixel line or/string **720** (shown to be linear with dashed line **721**).

Relative to vertical (or horizontal in some cases), the pixels **724** are arranged in the line/string **720** at an offset of 18.435 degrees (e.g., by placing a first pixel **724** at a location **612** and then stepping down (or up) three locations **612** in the same column and one location **612** over in a row to an adjacent column and then repeating this process to the edge/end of the map **610**). In this example, since sin 18.435 degrees=0.3162, the interlacing distance, $D_{Interlacing}$ as shown in FIG. **4** is given by $D_{Interlacing}=L_W/\sin a$ or $L_W/0.3162$. This provides about triple the space to print frames (pixels associated with frames) with the same lens size, L_W, and with the same resolution.

In FIG. **8**, a blank pixel map **610** again may be provided with a plurality of rows and columns of pixel locations (for pixels of a particular size to suit an output device resolution or the like). Diagram **800** shows a step of a non-orthogonal interlacing being performed to create a pixel map for a slant lens with an angular offset of 14.04 degrees (e.g., slant angle, a, is in the range of 10 and 15 degrees with about 14 degrees being more ideal). As shown, pixels **824** of a single frame/image of a set of frames/images being combined/interlaced are arranged as shown in a pixel line or/string **820** (shown to be linear with dashed line **821**).

Relative to vertical (or horizontal in some cases), the pixels **824** are arranged in the line/string **820** at an offset of 14.04 degrees (e.g., by placing a first pixel **824** at a location **612** and then stepping down (or up) four locations **612** in the same column and one location **612** over in a row to an adjacent column and then repeating this process to the edge/end of the map **610**). In this example, since sin 14.04 degrees=0.2426, the interlacing distance, $D_{Interlacing}$ as shown in FIG. **4** is given by $D_{Interlacing}=L_W/\sin a$ or $L_W/0.2426$. This provides about quadruple or four times the space to print frames (pixels associated with frames) with the same lens size, L_W, and with the same resolution.

In FIG. **9**, a blank pixel map **610** again may be provided with a plurality of rows and columns of pixel locations (for pixels of a particular size to suit an output device resolution or the like). Diagram **900** shows a step of a non-orthogonal interlacing being performed to create a pixel map for a slant lens with an angular offset of 45 degrees (e.g., slant angle, a, is in the range of 40 and 50 degrees with about 45 degrees being more ideal). As shown, pixels **924** of a single frame/image of a set of frames/images being combined/interlaced are arranged as shown in a pixel line or/string **920** (shown to be linear with dashed line **921**). Relative to vertical (or horizontal in some cases), the pixels **924** are arranged in the line/string **920** at an offset of 45 degrees (e.g., by placing a first pixel **924** at a location **612** and then stepping down (or up) one location **612** in the same column and one location **612** over in a row to an adjacent column and then repeating this process to the edge/end of the map **610**).

The arrangement of pixels in rows and columns presents some limitations as to the interlacing of the pixels, but it is likely that these four achievable slant or offset angles for use in interlacing pixels of the same image will prove beneficial in manufacturing lenticular products with slanted lenticules. The creation of the print file would then continue in each of these examples with selection of pixels of differing frames/images, and then arrangement of such pixels in a similar manner nearby to the pixels already positioned in the pixel map **610** until all (or most) of the pixel locations **612** are occupied.

FIG. **10** illustrates a pixel map or matrix of pixels **1000** arranged in a pattern useful for interlacing nine frames or images to provide the 18.435 degree, non-orthogonal configuration discussed with reference to FIG. **7**. In this example, nine frames are to be interlaced and printed in an ink or image layer for use with a lens sheet with slanted lenticules or slant lenses that are angled or offset from vertical by about 18.435 degrees. To this end, a single lens **1010** is shown positioned over the pixel map **1000**, and the longitudinal axis **1015** of the lens **1010** is shown to be at a slant or offset angle, θ, to vertical (but this could also be horizontal) **1013** of about 18.435 degrees. In the matrix **1000** the numbered pixels or pixel locations **1002** represent locations where pixels from interlaced images/frames would be located when printing is performed using a print file built upon the map or matrix **1000**.

Specifically, the matrix **1000** is used to interlace nine frames or images and numbers **1** through **9** are placed in each of the pixels or pixel locations **1002** in the map (e.g., each spot in the rows and columns of the map/matrix **1000**), with each like number representing a pixel from the same frame/image (e.g., all pixel locations **1002** filled with a "4" would correspond to pixels from a fourth frame/image) and at locations in such frame/image corresponding with the locations in the pixel map/matrix **1000**. For example, a "9" in the center of the map/matrix **1000** corresponds with a pixel in the ninth frame/image located in about the center of the frame/image. As another example, a "3" located in the lower left hand corner of the map/matrix **1000** corresponds with a pixel in the lower left hand corner of the third frame/image of the set of nine frames/images being combined to form an interlaced or combined print file.

The lens **1010** is useful for showing that pixels at pixel locations underneath the lens **1010** are aligned to be parallel with the longitudinal axis **1015** of the lens **1010** are concurrently visible while the interlacing is non-orthogonal (i.e., is along a column in the map/matrix **1000** (but could be along a row if the lens **1010** were angled from horizontal rather than vertical)). For example, as shown at **1040**, a set

of "9" pixels provided at the pixel locations **1040** in the map/matrix **1000** would be visible to a viewer via the lens **1010** from a particular point of view. In other words, following an inclination of 18.435 degrees in the map/matrix **1000** (and under the lens **1010** having this same slant to vertical **1013**) all the digits are the same within pixel locations (e.g., when used to create a print file the map/matrix **1000** calls for pixels from a single image to be aligned along an inclination of 18.435 degrees).

However, the interlacing of pixels is non-orthogonal to the lens longitudinal axis **1015** as shown with the set **1050** of interlaced pixels (or pixel locations in the map/matrix **1000**) that includes pixels from each frame/image. The interlacing process or algorithm may be generated based on the teaching of FIG. **7**, in this example, and it is performed to align pixels of like frames/images with the longitudinal axis of the lens **1010** while providing non-orthogonal or matrix interlacing of pixels of each of the frames/images across the lens **1010**.

The inventors noted during the interlacing process that repeating submatrices may be identified, and these may be repeated (e.g., placed side-by-side and stacked upon each other in a repetitive manner) to generate a map or matrix **1000** of a desired size and/or shape to suit a particular lens sheet. One exemplary interlacing submatrix is shown at **1060** that can be used in providing non-orthogonal interlacing of nine frames/images to suit a lens sheet with lenticules or lenses slanted to 18.435 degrees (i.e., to place pixels from each frame at inclines or angular offsets of 18.435 degrees for proper viewing through the lens **1010**). Similar pixel maps or matrices can readily be generated for other lens sheets with different angular slants or offsets from vertical (such as for 14.04 degrees, 26.57 degrees, and 45 degrees (with ranges of about 5 or more degrees on either side of these values)).

FIGS. **11**A and **11**B illustrate, schematically, end views of lenticular products or assemblies that may be fabricated using the non-orthogonal interlacing or matrix interlacing taught herein. As shown, the lenticular assembly or product **1100** includes a lens sheet or piece of lenticular material **1110** with a first (or top) side or surface with a plurality of lenticules or elongated lenses **1114** that are arranged to be angled or angularly offset ("slanted") relative to a vertical (or horizontal) axis of the lens sheet **1110**. For example, the lenticules **1114** may be slanted at 10 to 45 degrees, with some embodiments using slant angles of 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees for the lenticules **1114**.

The product **1100** further includes an interlaced image provided by printing an ink layer **1120** directly onto the second (or bottom) side or surface **1118** of the lens sheet **1110**. The ink layer **1120** is printed according to a print file or digital combined file in which a number of frames/images have been interlaced according to the teaching provided in this description. In one example, the lenses **1114** are provided at sizes associated with 75 LPI up to 2500 LPI, and the use of the non-orthogonal or matrix interlacing allows the thickness, t, of the lens sheet **1110** to be thinner than traditional interlacing as more information (or pixels) can be placed under each lens **1114**. For example, the thickness, t, may be relatively thick such as about 20 mils or be very thin down to about 10 microns and still provide 3D or other quality imagery with the printed layer or ink layer **1120** (e.g., the range of thicknesses, t, is about 10 micron to 20 mils). The lenticular product **1100** may then be laminated upon or attached to a substrate **1130** (such as a bank note or piece of currency) via film **1135** of transparent adhesive.

FIG. **11**B illustrates another lenticular product or assembly **1150** that may include the lens sheet **1110** with its slanted lenticules **1114** combined with the interlaced image in printed or ink layer **1120**. In this assembly **1150**, though, the ink **1120** is printed onto a substrate **1158**, and the lens sheet **1110** and substrate **1158** are assembled with a film of adhesive **1154**, with ink layer **1120** facing the second or back side **1118** of the lens sheet **1110**. In other words, the interlaced image may first be printed in a print step or process and then later assembled with the lens sheet **1110** to provide a lenticular assembly or product **1150**. The lenticular products **1100** and **1150** may take many forms to practice the present description. For example, the products **1100**, **1150** may take the form of security threads or stamps for use with currency or bank notes.

FIG. **11**C illustrates a lenticular product or assembly **1170** that may include the lens sheet **1110** with its slanted lenticules **1114** combined with the interlaced image in printed or ink layer **1120**. In this assembly **1170**, the ink **1120** is printed directly onto the back surface **1118** of the lens sheet **1110**. This relatively simple construction is useful for many objects/products **1170** such as a polymer bank note or another clear-to-translucent (or "transmissive") product (e.g., with a clear layer **1110**) that includes a printed image at the back **1118** of the lenses **1114** with an ink layer. As shown, the lenticular product or assembly **1170** may also include an additional layer of ink **1174** that may be used to provide an image that faces away from the lenses **1114** that can be viewed directly by an observer from the back side of the product **1170** (e.g., the side without lenses/lenticules **1114**), and this image may be a regular or conventional image that does not require lenses for proper viewing (focusing for the viewer on the image in the ink layer **1174** provided directly onto the printed ink layer **1120** or onto a clear or opaque substrate layer supporting or covering the ink layer **1174**).

In practice, the process of fabricating a lenticular product or assembly may involve first determining or knowing the resolution available to print a specific product and a thickness that is targeted or the goal thickness for the product. Then, based on these parameters or limitations, a "best" or useful option is chosen in terms of the specific angle or matrix that is to be used for the non-orthogonal or non-traditional slant lens interlacing. Next, the mechanical or real LPI lens is defined that will be produced and used in the product to match these product characteristics.

FIG. **12** illustrates a method **1200** for fabricating a lenticular product such as a security thread or stamp for currency or bank notes using the non-orthogonal printing of the present description. The method **1200** starts at **1205** such as with designing a desired image (e.g., 3D imagery), selecting or defining operating parameters of output device (e.g., resolution of a digital printer), selecting materials for the ink layer, lens sheet, and an adhesive/substrate if used. At step **1210**, the method **1200** continues with selecting the lenticular material to be used in the lenticular product. This may involve selecting a transparent plastic or synthetic material that has a particular thickness (e.g., 10 microns and up) such as a thickness of adjacent substrate(s) as in the case of a currency security thread or the like.

Step **1210** also involves defining or setting the size (i.e., LPI) of the lenticules on the surface of the lenticular material and also defining or setting the slant or offset angle for each lenticule. As discussed above, it may be useful to use a slant angle of 10 to 45 degrees with angles of 14.04 degrees,

18.435 degrees, 26.57 degrees, and 45 degrees for the lenticules being well suited to the non-orthogonal or matrix interlacing.

At step **1220**, the method **1200** involves selecting a number of frames (or digital image files) to use in creating a visual effect with the lenticular material selected in step **1210**. To provide 3D imagery, it may be desirable to select 6 to 12 or more frames, and the number of frames may be selected (or limited) by the size of the pixels achievable with the output device (DPI of the printer selected in step **1205**). Note, steps **1205**, **1210**, and **1220** may be performed in a fully or partially concurrent matter due to the interrelationships between the parameters/characteristics of a lenticular product (e.g., LPI, DPI, lens size, and angular offset) as discussed in detail above.

At step **1230**, the method **1200** continues with generating a matrix of pixels (or pixel map) for use in interlacing the selected frames from step **1220**. This pixel matrix may take the form of matrix **1000** (e.g., if the number of frames is nine and the slant angle is 18.435 degrees) or may be generated following the processes described with reference to FIGS. **5-9** to suit a particular slant angle and number of frames (as well as other parameters such as lens size). The pixel matrix may then be stored as a digital file for use in later steps. In some cases, a plurality of pixel matrices or pixel maps may be generated for each combination of interlacing parameters, and the matching pixel matrix may be retrieved from memory at step **1230** (e.g., one skilled in the art may generate pixel matrices to suit each lens sheet they may use in future fabrication processes as well as pixel matrices suited to differing numbers of frames, lens sizes, and output device resolutions).

At step **1240**, the method **1200** continues with generating a print file for controlling an output device (e.g., a digital printer) to print an interlaced image. This may involve performing non-orthogonal interlacing of the frames/images chosen in **1220** using the pixel matrix of step **1230**. Each frame of step **1220** may pixilated (e.g., divided into a number of pixels matching that of the pixel map for each frame) and then these pixels may be plugged into pixel locations for corresponding pixels from the frames defined in the pixel map.

The method **1200** can then continue at **1250** by using the digital print file from step **1240** to operate an output device to print an interlaced image (an ink layer with pixels from each frame printed according to the pixel matrix). The printed image may be provided directly on the planar, back side of a sheet of the lenticular material selected in step **1210** or it may be printed onto a substrate. Then, in step **1260**, the lenticular product may be completed such as by attaching the lens sheet with its printed ink layer to a substrate (laminate lens with interlaced image on another object such as a security stamp onto a bank note). In other cases, step **1260** may involve attaching a substrate upon which the interlaced image was printed onto the back of a lens sheet/lenticular element with a transparent (or at least highly translucent) adhesive. The method **1200** may then end at **1290** or may continue at step **1210** (e.g., selecting a different lenticular material such as with lenticules at a different slant angle or with lenticules of a different size or a sheet with a different thickness) or step **1220** (e.g., selecting a different set of frames or different number of frames to create a lenticular product).

FIG. **13** illustrates a functional block diagram of a system **1300** useful for printing an image onto a substrate or lens sheet with an interlacing pattern as described herein. The system **1300** includes a controller **1310** which may take the form of nearly any computing device specially configured as shown. The controller **1310** includes a processor **1312** executing computer programs or readable code to perform the functions of an interlacing module **1320**. The controller **1310** also controls or manages one or more input/output devices **1314** such as a keyboard, a mouse, a touch pad and/or touch screen, a monitor, and a user interface provided graphically on the monitor to allow an operator to interact with the controller (e.g., initiate the interlacing module, provide input such as to select a lenticular material with its slanted lenticules, select frames for interlacing under the lenticular material, and so on). The CPU **1312** also manages operation of memory **1330** which may store the code for module **1320** in readable format.

In the memory **1330**, a set of lenticular material data **1332** is stored that defines parameters or characteristics of a lens sheet upon which an interlaced image will be printed. For example, the data **1332** may include the lens size (e.g., LPI used to form the lens sheet), the thickness (e.g., 10 to 2500 microns or the like), and the slant or offset angles of the lenticules of the lens sheet. The memory **1330** also stores a number of frames or images in digital form that are to be interlaced with the interlacing module **1320**, and these images/frames **1340** may be selected from a larger set (not shown) by the user of the controller via user input with I/O **1314**. Each of the frames/images is digital and is made up of a number of pixels (which may be selected to have a number or resolution similar to the pixel map **1350** or a subset of the pixels **1345** may be used in the interlaced or print file **1360**).

The memory **1330** further is used to store a pixel matrix **1350** generated by the interlacing module **1320**, and the pixel matrix **1350** may take the form of matrix **1000** of FIG. **10** and may be generated by the interlacing module **1320** as discussed with reference to any of FIGS. **5-10** and **12**. The interlacing module **1320** may further operate to generate a print file **1360** from the frames/images **1340** and the pixel matrix **1350**, e.g., by selecting pixels **1345** from each image and placing them in corresponding pixel locations in the pixel matrix **1350** (which is selected to suit the slant angel **1338**, the number of frames **1340**, and the lens size **1334**).

As shown, the system **1300** further includes an output device **1380** such as a printer with a particular DPI resolution (or multiple resolutions). The controller **1310** acts to transmit control signals **1370** based on the print file **1360** to the output device **1380**. Input **1382** is provided to the controller **1380** in the form of a substrate or a lens sheet **1384**, and the output device **1380** prints ink onto the substrate or planar side of the lens sheet **1384** in the pattern defined by the control signals **1370** (e.g., the print file **1360**). Upon completion of printing, the output device **1380** outputs **1386** a product/assembly **1390** made up of the substrate or lens sheet **1384** and an ink layer **1394** providing the printed interlaced image.

From the above description, it will be understood that for many years lenticular optics have been used with interlaced printed images or as a print medium. The general costs are high relative to normal printing because of the expense of the material. In addition, making thinner lenses work with limited resolution in a digital device or with traditional plate setting equipment makes it very difficult if not impossible to print interlaced images on very thin lens arrays or lens sheets because it is not supported by the traditional interlacing mathematics and corresponding lens arrays.

In contrast, the present invention and description combines an angled lens or lenticule with stair-stepped interlacing or display of images (e.g., see the interlacing of FIGS. **5-10**) to allow two to four times the amount of data to be

printed under the slant/angled lens or lenticule when compared with traditional interlacing. Conversely, the non-traditional (or non-orthogonal) interlacing taught herein supports a reduction in lens sheet thickness of up to or more than two thirds (up to 67 percent or more thickness reduction) to achieve the same imagery provided by a much thicker lens sheet or array with traditional slant lens interlacing. Hence, more than half and up to two thirds of the cost of producing traditional lens arrays can be eliminated.

The non-orthogonal or matrix interlacing for slant lens taught herein teaches that when a lens sheet is formed with lenses made at set or predefined angles the corresponding pixels should be placed under the lenses in a grid format (e.g., see FIG. **10** for one useful pixel mapping for 9 frames under lenses at a slant angle of 18.435 degrees (or 15 to 20 degrees)). The grid format or pixel matrix is designed so that the like pixels or pixels of a single frame are aligned with the lens or parallel to its longitudinal axis. In this way, one can use up to two thirds (or 67 percent) less print resolution to accomplish the same graphic or can take up to two thirds (or 67 percent) of the mass out of the lens array and accomplish the same imagery.

For example, a digital web lens at only 5 mils can be made to print on an HP® Indigo output device at about 812 DPI using nine frames with a mechanical LPI of about 270 LPI. The lens will each focus at 5 mils but printing this web lens with traditional slant lens interlacing is impossible with nine frames (which is a useful number of frames for 3D imagery). Normally, with traditional interlacing, the DPI necessary to print this lens would be LPI multiplied by frame count or, in this case, 270 LPI multiplied by 9 frames or 2430 DPI. In contrast, the non-orthogonal or matrix interlacing taught herein matched with the angle of the slant lens can be used to support a print resolution that is about one third that required with traditional interlacing or, in this case, a resolution of 810 DPI is useful (which is less than the resolution provided by existing output devices of 812 DPI). In other words, the resolution of the printer or output device can be matched nearly exactly using the non-orthogonal or matrix interlacing described above.

As taught, slant lenses can be engraved and indexed or made with a slight offset (e.g., like a screw) between 80 LPI and 1500 LPI, for example, at angles between about 10 and 46 degrees. An interlaced print file can be generated from a pixel matrix or map adapted for the slant angle of the lenses or lenticules in the lens sheet to provide non-orthogonal interlacing of pixels of differing frames as well as to correspond with the lens size (set by LPI) and number of frames/images to be interlaced. The description further teaches how to form or print an interlaced image with a number of pixels or amount of data that is at least double that achieved with traditional interlacing for slant lens. For example, a much larger number of frames or pixels associated with such frames may be printed non-orthogonally (e.g., along a vertical or column rather than orthogonally to the longitudinal axis of the slant lens as in traditional interlacing), with some embodiments using 6, 9, or 16 images/frames to produce an interlaced image using a pixel matrix or map. The interlaced image printed according to this description results in a lower DPI, by using the stepwise or stairway effect of interlacing, than with traditional slant lens interlacing formulas (e.g., DPI=2 LPI×Frame Count).

At this point, it may be useful to list some anticipated results that are achievable with the non-orthogonal or matrix/grid interlacing techniques. A lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 14.04 degrees (such that the sine value is 0.2426). An interlaced image may be provided using 16 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 16 by 16 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 4.122. If the mechanical (or actual) LPI of the lens sheet is 77.5 LPI (or a lens chord width or size of 0.012903 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 18.801553 and, as a result, the DPI is 300.824 (with a dot size of 0.003324 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.05319 inches (as determined by (1/mechanical LPI)/sin 14.04 degrees).

In another example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 14.04 degrees (such that the sine value is 0.2426). An interlaced image may be provided using 16 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 16 by 16 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the SR is again 4.122. If the mechanical (or actual) LPI of the lens sheet is now 400 LPI (or a lens chord width or size of 0.0025 inches), the effective LPI for interlacing is 97.040272 and, as a result, the DPI is 1552.640 (with a dot size of 0.000644 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.01031 inches (as determined by (1/mechanical LPI)/sin 14.04 degrees).

In another example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 14.04 degrees (such that the sine value is 0.2426). An interlaced image may be provided using 16 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 16 by 16 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the SR is again 4.122. If the mechanical (or actual) LPI of the lens sheet is now 654.5 LPI (or a lens chord width or size of 0.001528 inches), the effective LPI for interlacing is 158.782145 and, as a result, the DPI is 2540.507 (with a dot size of 0.000394 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00630 inches (as determined by (1/mechanical LPI)/sin 14.04 degrees).

In still another example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 14.04 degrees (such that the sine value is 0.2426). An interlaced image may be provided using 16 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 16 by 16 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the SR is again 4.122. If the mechanical (or actual) LPI of the lens sheet is now 619.51 LPI (or a lens chord width or size of 0.001614 inches), the effective LPI for interlacing is 150.293547 and, as a result, the DPI is 2404.690 (with a dot size of 0.000416 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00665 inches (as determined by (1/mechanical LPI)/sin 14.04 degrees).

In other cases, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 18.435 degrees (such that the sine value is 0.3162). An interlaced image may be provided using 9 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 9 by 9 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 3.16260. If the mechanical (or actual) LPI of the lens sheet is 210 LPI (or a lens chord width or size of 0.004762 inches), the

effective LPI for interlacing (mechanical LPI divided by SR) is 66.401062 and, as a result, the DPI is 597.618 (with a dot size of 0.001673 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.01506 inches (as determined by (1/mechanical LPI)/sin 18.435 degrees).

In another example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 18.435 degrees (such that the sine value is 0.3162). An interlaced image may be provided using 9 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 9 by 9 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 3.16260. If the mechanical (or actual) LPI of the lens sheet is 285.71 LPI (or a lens chord width or size of 0.003500 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 90.340226 and, as a result, the DPI is 813.074 (with a dot size of 0.001230 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.01107 inches (as determined by (1/mechanical LPI)/sin 18.435 degrees).

In a similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 18.435 degrees (such that the sine value is 0.3162). An interlaced image may be provided using 9 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 9 by 9 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 3.16260. If the mechanical (or actual) LPI of the lens sheet is 446.28 LPI (or a lens chord width or size of 0.002241 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 141.111744 and, as a result, the DPI is 1270.024 (with a dot size of 0.000787 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00709 inches (as determined by (1/mechanical LPI)/sin 18.435 degrees).

In another similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 18.435 degrees (such that the sine value is 0.3162). An interlaced image may be provided using 9 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 9 by 9 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 3.16260. If the mechanical (or actual) LPI of the lens sheet is 252 LPI (or a lens chord width or size of 0.003968 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 79.681275 and, as a result, the DPI is 717.142 (with a dot size of 0.001394 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.01255 inches (as determined by (1/mechanical LPI)/sin 18.435 degrees).

In yet another similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 18.435 degrees (such that the sine value is 0.3162). An interlaced image may be provided using 9 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 9 by 9 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 3.16260. If the mechanical (or actual) LPI of the lens sheet is 845 LPI (or a lens chord width or size of 0.001183 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 267.185227 and, as a result, the DPI is 2404.701 (with a dot size of 0.000416 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00374 inches (as determined by (1/mechanical LPI)/sin 18.435 degrees).

In other cases, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 26.57 degrees (such that the sine value is 0.4473). An interlaced image may be provided using 6 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 6 by 6 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 2.23560. If the mechanical (or actual) LPI of the lens sheet is 111.7 LPI (or a lens chord width or size of 0.008953 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 49.964215 and, as a result, the DPI is 299.780 (with a dot size of 0.003336 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.02001 inches (as determined by (1/mechanical LPI)/sin 26.57 degrees).

In a similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 26.57 degrees (such that the sine value is 0.4473). An interlaced image may be provided using 6 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 6 by 6 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 2.23560. If the mechanical (or actual) LPI of the lens sheet is 223.5 LPI (or a lens chord width or size of 0.004474 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 99.973162 and, as a result, the DPI is 599.829 (with a dot size of 0.001667 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.01000 inches (as determined by (1/mechanical LPI)/sin 26.57 degrees).

In another similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 26.57 degrees (such that the sine value is 0.4473). An interlaced image may be provided using 6 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 6 by 6 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 2.23560. If the mechanical (or actual) LPI of the lens sheet is 473.2 LPI (or a lens chord width or size of 0.002113 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 211.665772 and, as a result, the DPI is 1269.974 (with a dot size of 0.000787 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00472 inches (as determined by (1/mechanical LPI)/sin 26.57 degrees).

In yet another similar example, a lenticular product or assembly may be formed using a lens sheet with lenticules slanted at a slant angle of 26.57 degrees (such that the sine value is 0.4473). An interlaced image may be provided using 6 frames or images, such that the submatrix that is repeated in the pixel matrix or map is 6 by 6 pixels in size (e.g., see FIG. **10** where a 9 by 9 pixel submatrix **1060** is repeated). In this case, the step ratio (SR) or the increase in the amount of interlaced data when compared with traditional interlacing is 2.23560. If the mechanical (or actual) LPI of the lens sheet is 894 LPI (or a lens chord width or size of 0.001119 inches), the effective LPI for interlacing (mechanical LPI divided by SR) is 399.892646 and, as a result, the DPI is 2399.317 (with a dot size of 0.000417 inches) with the vertical interlacing distance, $D_{Interlacing}$, of 0.00250 inches (as determined by (1/mechanical LPI)/sin 26.57 degrees).

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

The matrix for a 45 degree offset or slant angle typically would be 5 by 5 frames (or 5×5 pixels). Note, also, there are some cases where using the techniques described herein allows one to gain more space than the minimum requirement. For example, when a multiple of each matrix is used to generate the pixel matrix or map, the overall pixel matrix or map would be a multiple of the base or submatrix, e.g., a 9 by 9 pixel submatrix may be repeated in a 18 by 18 pixel matrix or pixel map (which is a multiple of the 9 by 9 repeated pattern or submatrix).

In FIGS. **4**, **5**, **10**, **11**A, and **11**B, the lens sheets were all shown and described as including linear (or elongated) lenses or lenticules that were arranged to be slanted (e.g., not orthogonal to an edge of the lens sheet). The inventors recognized that there are many applications where it is desirable to use lenses (e.g., microlenses when trying to achieve a very thin lens sheet) that are not linear or are not lenticules.

While other interlacing techniques may be used with such lenses, it was determined through analysis and experimentation that the pixel matrices or maps described above could be effectively used to provide or print interlaced images that can then be viewed through non-linear lenses (not lenticules). However, the non-linear lenses or microlenses have to be arranged in a specific pattern to provide proper viewing of the pixels in a manner similar to that achieve with slanted lenticules. Specifically, lens sheets are designed and produced in which the non-linear lenses are arranged in a plurality of side-by-side (and parallel) sets of lenses, with each set of lenses being slanted on the exterior surface of the lens sheet (or lens material).

In other words, a line passing through a center point of each lens in a lens set is at an angle relative to a side or edge of the lens sheet or lens material. This line is similar to a longitudinal axis of one of the lenticules described above, and these lines passing through different sets of lenses are parallel to each other. As with the lenticules, the slant angle would fall within a range of 10 to 46 degrees from a vertical or a horizontal axis (or side or edge) of the lens sheet. The pixel maps or matrices shown in FIGS. **6-9** may be used with these slanted sets of lenses, and, in such cases, the slant angle may be in the range of 14 to 15 degrees, in the range of 18 to 19 degrees, in the range of 26 to 27 degrees, and in the range of 44 to 46 degrees, respectively. In particular implementations of the optical product (when sets of non-linear lenses are used the product would be labeled as an optical product rather than a lenticular product), the slant angle of the lens sets is 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees.

Lens sheets manufactured with slanted lens sets would be used to produce the optical products such as those shown at **1100**, **1150** in FIGS. **11**A and **11**B with the lenticular material, lens sheet, or lens film **1110** replaced with lens sheet(s)/film(s) with slanted lens sets. Similarly, the method **1200** of manufacturing a lenticular product would be modified to produce optical products by changing step **1210** to select lens sheets or lens material with slanted sets of non-linear lenses (e.g., replace "lenticules" with slanted set of lenses). Additionally, the system **1300** of FIG. **13** can readily be modified to produce optical products **1390** by replacing the lens sheet **1384** with lenticules with one formed with slanted sets of lenses.

FIG. **14** illustrates, in a schematic manner, an optical product **1400** that implements these concepts. As shown, the optical product **1400** includes lens sheet or material (e.g., a transparent-to-transmissive (or translucent) film) **1410** with an upper surface **1414** that is fabricated to include a plurality of round-based, non-linear lenses or microlenses **1422** (or round lenses) in place of lenticules. The product **1400** also includes an ink layer underneath the lens sheet **1410**, and the ink layer is printed using a pixel map or matrix of pixels as described for map **1000** of FIG. **10**. Particularly, the pixels such as pixels **1456** are arranged in 9 by 9 matrices as shown with matrix **1450**. In this way, the pixels are arranged in a pattern useful for interlacing nine frames or images to provide the 18.435 degree, non-orthogonal configuration discussed with reference to FIG. **7**. In this example, nine frames are to be interlaced and printed in an ink or image layer for use with the lens sheet **1410** with slanted sets of lenses or lens sets **1420**, **1430**, **1434**, **1438** that are angled or offset from vertical by about 18.435 degrees (i.e., θ equals 18.435 degrees in this example).

To this end, lens set **1420** is shown positioned over the ink layer formed based on the pixel map (e.g., pixel map **1000** of FIG. **10**. A single lenticule or elongated lens **1440** is shown over the top of the lens set **1420**. This is useful for showing that the set **1420** of round lenses **1422** can be used to replace the lenticule **1440**. The longitudinal axis of the lenticule **1440** coincides with a line **1423** passing through the center or center point of each of the lenses **1422** in the lens set **1420**. The line **1423** is shown to be at a slant or offset angle, θ, to vertical (but this could also be horizontal) **1424** of about 18.435 degrees. In the matrix **1450**, the numbered pixels or pixel locations **1456** represent locations where pixels from interlaced images/frames would be located when printing the print layer as may be performed using a print file built upon the map or matrix **1450**.

Specifically, the matrix **1450** is used to interlace nine frames or images and numbers **1** through **9** are placed in each of the pixels or pixel locations **1456** in the map (e.g., each spot in the rows and columns of the map/matrix), with each like number representing a pixel from the same frame/image (e.g., all pixel locations **1456** filled with a "4" would correspond to pixels from a fourth frame/image) and at locations in such frame/image corresponding with the locations in the pixel map/matrix. For example, a "9" in the center of the map/matrix corresponds with a pixel in the ninth frame/image located in about the center of the frame/image. As another example, a "3" located in the lower left hand corner of the map/matrix corresponds with a pixel in the lower left hand corner of the third frame/image of the set of nine frames/images being combined to form an interlaced or combined print file.

As can be seen (and as discussed with regard to FIG. **10**), pixels at pixel locations underneath the lenses **1422** of set **1420** (and other sets **1430**, **1434**, **1438**) are aligned to be parallel with the line **1423** passing through the center of the lenses **1422** and are concurrently visible while the interlacing is non-orthogonal (i.e., is along a column in the map/matrix (but could be along a row if the lens set **1420** was angled from horizontal rather than vertical)). For example, a set of "9" pixels provided at the pixel locations in the map/matrix (and corresponding printed ink layer) would be visible to a viewer via the lens set **1420** from a particular point of view. In other words, following an inclination of 18.435 degrees in the map/matrix (and under the lens set **1420** having this same slant to vertical **1424**) all the digits

are the same within pixel locations (e.g., when used to create a print file the map/matrix calls for pixels from a single image to be aligned along an inclination of 18.435 degrees).

However, the interlacing of pixels is non-orthogonal to the lens center line **1423** as shown with the set **1480** of interlaced pixels (or pixel locations in the map/matrix and corresponding printed ink layer) that includes pixels from each frame/image. The interlacing process or algorithm may be generated based on the teaching of FIG. **7**, in this example, and it is performed to align pixels of like frames/images with the center line **1423** of the lens set **1420** while providing non-orthogonal or matrix interlacing of pixels of each of the frames/images across the lenses **1422** in the lens set **1420**. Note, all nine pixels in the set **1480** are not visible under a single lens **1422**, with the example of FIG. **14** showing an implementation where three lenses are covering the nine interlaced pixels. In some cases, though, it may be useful to size and align the lenses **1422** in some implementations of the optical product **1400** so that each lens **1422** covers one pixel from each image or frame being interlaced. In the example of FIG. **14**, each lens **1422** covers or is over a set of nine pixels associated with nine different images/frames. When the printed image is viewed through the lenses, each lens **1422** in the set is used to display a single pixel from a like image/frame (e.g., each lens **1422** displays the "5" pixels and then the "3" pixels and so on).

As discussed above, the inventors noted during the interlacing process that repeating submatrices may be identified, and these may be repeated (e.g., placed side-by-side and stacked upon each other in a repetitive manner) to generate a map or matrix as shown in FIG. **14** of a desired size and/or shape to suit a particular lens sheet. One exemplary interlacing submatrix is shown at **1450** that can be used in providing non-orthogonal interlacing of nine frames/images to suit a lens sheet with lenticules or lenses slanted to 18.435 degrees (i.e., to place pixels from each frame at inclines or angular offsets of 18.435 degrees for proper viewing through the lens sets **1420**, **1430**, **1434**, **1438**). Similar pixel maps or matrices can readily be generated for other lens sheets with different angular slants or offsets from vertical (such as for 14.04 degrees, 26.57 degrees, and 45 degrees (with ranges of about 5 or more degrees on either side of these values)).

In designing the lenses **1422** for use on the surface **1414** of the lens sheet **1410**, it may be useful to arrange and size the lenses **1422** in each set **1420**, **1430**, **1434**, **1438** to replace a slanted lenticule **1440**. For example, a particular LPI may be chosen or defined as discussed herein, and this would provide a lenticule or linear lens width, W. Then, round lenses such as lenses **1422** may be chosen that have a lens radius that is about one half of this lenticule width, W. The pattern of lenses **1422** with such a radius is selected to provide sets **1420**, **1430**, **1434**, **1438** that are each arranged in a linear pattern such that a line passes through a center point of each lens **1422** in a particular set **1420**, **1430**, **1434**, **1438** as shown with line **1423**. Further, such "center lines" of the sets **1420**, **1430**, **1434** and **1438** of linearly arranged lenses **1422** would all be parallel to each other. Also, as shown, there typically would be little to no space between the lenses **1422** within a set **1420**, **1430**, **1434**, **1438** or between lenses of side-by-side sets (e.g., the lenses **1422** of sets **1420** and **1430** are shown with their bases contacting each other).

The inventors further recognized that lenses with other base shapes may be useful in optical products (in place of the slanted lenticules). For example, FIG. **15** shows an optical product **1500** in which the lens sheet **1410** is replaced with a lens sheet **1510** with an upper surface (or surface opposite its planar bottom surface) **1514** that is fabricated with a plurality of non-linear lenses or microlenses **1522**. The lenses **1522** are configured with hexagonal bases instead of round bases.

As with the lens sheet **1410**, the lenses **1522** of the lens sheet **1510** are linearly arranged (or arranged in a line or row) in a pattern such that a line **1523** passes through the center of each lens **1522** in a set **1520**. Further, this center line **1523** of the set **1520** is at a slant angle, θ, and not orthogonal to the edges of the sheet **1510** (or to vertical or horizontal axes of the sheet **1510**). As shown, the slant angle, θ, is again 18.435 degrees (but the entire range of slant angles discussed herein may be used to produce the sheet **1510**). Each set **1520**, **1530**, **1534**, **1538** is arranged with their center lines parallel to each other. The lenses **1522** are used to replace or instead of the lenticule **1440**, and, to this end, each of the lenses **1522** may have a width, W_{Hex} (as measured between opposite corners of the hexagonal base) that matches the lenticule width, W. Within a set such as set **1520**, the lenses **1522** may be arranged with abutting sides while adjacent sets may be nested together with as shown (e.g., with adjacent rows staggered or offset along their center lines such that an external corner of an adjacent lens is received where two lenses mate in the neighboring set).

As another lens shape example, FIG. **16** shows an optical product **1600** in which the lens sheet **1410** is replaced with a lens sheet **1610** with an upper surface (or surface opposite its planar bottom surface) **1614** that is fabricated with a plurality of non-linear lenses or microlenses **1622**. The lenses **1622** are configured with square bases instead of round or hexagonal bases. As with the lens sheet **1410**, the lenses **1622** of the lens sheet **1610** are linearly arranged (or arranged in a line or row) in a pattern such that a line **1623** passes through the center of each lens **1622** in a set **1620**. Further, this center line **1623** of the set **1620** is at a slant angle, θ, and not orthogonal to the edges of the sheet **1610** (or to vertical or horizontal axes of the sheet **1610**). As shown, the slant angle, θ, is again 18.435 degrees (but the entire range of slant angles discussed herein may be used to produce the sheet **1610**).

Each set **1620**, **1630**, **1634**, **1638** is arranged with their center lines parallel to each other. The lenses **1622** are used to replace or instead of the lenticule **1440**, and, to this end, each of the lenses **1622** may have a width, W_{Square} (as measured between opposite corners of the hexagonal base) that matches the lenticule width, W. Within a set such as set **1620**, the lenses **1622** may be arranged or stacked with abutting sides (and two co-linear sides or edges) while being aligned (not staggered from) with the lenses of adjacent or neighboring sets as shown in the example of FIG. **16**. As shown at **1675**, pixels from a particular frame (here Frame **6**) are visible as the lenses **1622** of set **1630** are focusing along the slant angle, θ, and this would be valid for all other frames, too.

For any type of lens (e.g., linear or lenticule, round base, hexagonal base, or square base) using the same mechanical LPI number (or lenticule width, round base diameter, hexagonal base width, or square base width), the vertical distance can be adjusted to fit the number of frames being interlaced (via slant interlacing as described herein). The adjustment is performed without changing the lens size in this case. Instead, with the same lens size, the slant angle is changed to suit the number of frames for a particular lens or lens set.

For example, the vertical distance can be increased by decreasing the magnitude of the slant angle and can be decreased by increasing the magnitude of the slant angle

(e.g., more pixels can be placed in a vertical column (or horizontal row if slanting is from horizontal rather than vertical) when a slant angle of about 14 degrees is used than when a slant angle of 45 degrees is used). In other cases, scaling can be performed to adjust the "size" of the column of pixels or, in other words, the size of the matrix or map of pixels from the frames or images. In this manner, an optical product can be designed and then fabricated that has a lens sheet with different slant angles and/or with the number of frames (and associated number of pixels) adjusted to provide a desired resolution while still fitting within the vertical distance available underneath the lenticules or lenses in each lens set for interlacing a column of pixels.

We claim:

1. An optical product, comprising:

a lens sheet comprising a first side having a plurality of side-by-side sets of linearly arranged lenses with each of the sets at a slant angle from an axis of the lens sheet, wherein each of the sets of linearly arranged lenses has an axis extending through the linearly arranged lenses and a lens width as measured by a line extending orthogonal to a longitudinal axis across one of the lenses; and

an ink layer, proximate to a second side of the lens sheet opposite the first side, comprising pixels from a plurality of digital images, wherein the pixels are arranged in a pattern of pixel locations providing non-orthogonal interlacing of the digital images relative to each of the sets of the linearly arranged lenses, wherein each of the patterns of pixel locations extends along a line that is transverse and non-orthogonal to the longitudinal axis of one of the sets of linearly arranged lenses.

2. The optical product of claim **1**, wherein the pattern of pixel locations is adapted to align a number of the pixels from each of the digital images to be parallel to a line extending through a center of the linearly arranged lenses in an adjacent one of the sets of the linearly arranged lenses, whereby the number of pixels is greater than a number of pixels available using interlacing orthogonal to the line extending though the center of the linearly arranged lenses.

3. The optical product of claim **1**, wherein each of the linearly arranged lenses has a round, hexagonal, or square base.

4. The optical product of claim **1**, wherein the lens sheet has a thickness in the range of 10 to 2500 microns and the sets of the linearly arranged lenses are provided on the first side at 75 to 1500 LPI.

5. The optical product of claim **4**, wherein each of the linearly arranged lenses has a size parameter matching an LPI of the sets of the linearly arranged lenses.

6. The optical product of claim **1**, wherein the plurality of digital images comprises a number of images selected from the range of 5 images to 16 images and wherein the non-orthogonal interlacing is provided by sets of the pixels equal in number to the number of images including at least one pixel from each of the plurality of digital images.

7. The optical product of claim **6**, wherein the sets of the pixels providing the non-orthogonal interlacing are aligned in a row or in a column of the pattern of pixel locations.

8. The optical product of claim **6**, wherein the pattern of pixel locations comprises a pixel matrix repeating submatrices of the sets of the pixels a number of times.

9. The optical product of claim **1**, wherein the slant angle falls within a range of 14 to 15 degrees, a range of 18 to 19 degrees, a range of 26 to 27 degrees, or a range of 44 to 46.

10. The optical product of claim **9**, wherein the slant angle is 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees.

11. The optical product of claim **1**, wherein the slant angle is in the range of 10 to 46 degrees and wherein each of the patterns of pixel locations is linear.

12. The optical product of claim **1**, wherein the line has a length that is greater than the lens width.

13. An assembly, comprising:

a lens film comprising a plurality of side-by-side sets of linearly arranged lenses with each of the sets at a slant angle; and

an ink layer, opposite the sets of the linearly arranged lenses, comprising pixels from a plurality of images,

wherein each of the sets of linearly arranged lenses has a lens width as measured by a line extending orthogonal to a longitudinal axis across one of the lenses,

wherein the pixels are arranged in a pattern of pixel locations providing non-orthogonal interlacing of the images relative to the sets of the linearly arranged lenses,

wherein pattern of pixel locations provides sets of the pixels that each extends linearly across one of the sets of linearly arranged lenses along a line having a length greater than a width of each of the sets of the linearly arranged lenses, and

wherein the pattern of pixel locations is adapted to align a number of the pixels from each of the digital images to be parallel to a line extending through a center of the linearly arranged lenses in an adjacent one of the sets of the linearly arranged lenses.

14. The assembly of claim **13**, wherein each of the linearly arranged lenses has a round base, a hexagonal base, or a square base.

15. The assembly of claim **13**, wherein the lens film has a thickness in the range of 10 to 2500 microns and the sets of the linearly arranged lenses are provided on the first side at 75 to 1500 LPI and wherein each of the linearly arranged lenses has a size parameter matching an LPI of the sets of the linearly arranged lenses.

16. The assembly of claim **13**, wherein the plurality of digital images comprises a number of images selected from the range of 5 images to 16 images and wherein the non-orthogonal interlacing is provided by sets of the pixels equal in number to the number of images including at least one pixel from each of the plurality of digital images.

17. The assembly of claim **13**, wherein the slant angle is 14.04 degrees, 18.435 degrees, 26.57 degrees, or 45 degrees.

18. The assembly of claim **13**, wherein the slant angle is within a range of 14 to 15 degrees, a range of 18 to 19 degrees, a range of 26 to 27 degrees, or a range of 44 to 46 degrees.

19. An optical product, comprising:

a lens sheet comprising a first side having a plurality of side-by-side sets of linearly arranged lenses with each of the sets at a slant angle in the range of 10 to 46 degrees from an axis of the lens sheet, wherein each of the sets of linearly arranged lenses has an axis extending through the linearly arranged lenses and a lens width as measured by a line extending orthogonal to a longitudinal axis across one of the lenses; and

an ink layer, proximate to a second side of the lens sheet opposite the first side, comprising pixels from a plurality of digital images,

wherein the pixels are arranged in a plurality of patterns of pixel locations with each of the patterns of pixel locations extending along a line that is transverse and

non-orthogonal to the longitudinal axis of one of the sets of linearly arranged lenses, and

wherein the length of the line is at least double the lens width.

20. The optical product of claim **19**, wherein the length of the line is at least triple the lens width.

21. The optical product of claim **19**, wherein a step ratio, defining an increase in an amount of interlaced data when compared with traditional interlacing, is provided by the optical product that is greater than 4 when the slant angle is in the range of 14 to 15 degrees, is greater than 3 when the slant angle is in the range of 18 to 19 degrees, and is greater than 2 when the slant angle is in the range of 26 to 27 degrees.

22. The optical product of claim **19**, wherein each of the linearly arranged lenses has a round, hexagonal, or square base.

23. The optical product of claim **19**, wherein the plurality of digital images comprises a number of images selected from the range of 5 images to 16 images, wherein the non-orthogonal interlacing is provided by sets of the pixels equal in number to the number of images including at least one pixel from each of the plurality of digital images, and wherein the pattern of pixel locations comprises a pixel matrix repeating submatrices of the sets of the pixels a number of times.

24. The optical product of claim **19**, wherein each of the linearly arranged lenses has a round base.

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